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Buried Waste Integrated Demonstration Human Engineered Control Station Final Report

Human Engineered Control Station Team

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EG&G Idaho, Inc.
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DISCLAIMER

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Prepared by

Reva Hyde — 9/26/94

R. A. Hyde, Senior Engineer, Technical Lead
Mechanical Engineering
Date

Reviewed by

J K Rawlins by SBG — 9/28/94

J. K. Rawlins, Principal Investigator
Mechanical Engineering
Date

for B. E. Griebenow — 9/28/94

B. E. Griebenow, Technical Liaison - Retrieval
Buried Waste Integrated Demonstration
Date

Approved by

9/28/94

K. M. Kostelnik, Coordinator
Buried Waste Integrated Demonstration
Date

ABSTRACT

This document describes the Human Engineered Control Station (HECS) project activities including the conceptual designs. The purpose of the HECS is to enhance the effectiveness and efficiency of remote retrieval by providing an integrated remote control station. The HECS integrates human capabilities, limitations, and expectations into the design to reduce the potential for human error, provides an easy system to learn and operate, provides an increased productivity, and reduces the ultimate investment in training. The overall HECS consists of the technology interface stations, supporting engineering aids, platform (trailer), communications network (broadband system), and collision avoidance system.

SUMMARY

The Human Engineered Control Station (HECS) was designed to support the Buried Waste Integrated Demonstration (BWID) scheduled for fiscal year (FY) 1995 and to later support environmental restoration and remediation of various U.S. Department of Energy (DOE) sites. The HECS is a mobile control station that houses various remote equipment needed to remediate (characterize and retrieve) buried waste. The HECS consists of remote control mechanisms for a gantry crane and its subsystems, an excavator, a conveyance system, and other support systems. The project consisted of the following activities: task clarification, conceptual designs for the interfaces, conceptual designs for the platform engineering issues, concepts for a collision avoidance system, and a conceptual design for a communications network to transfer data and video from the containment building to the control station.

The objective of the HECS is to enhance operator effectiveness and efficiency by providing an integrated remote control mechanism that integrates human capabilities, limitations, and expectations into the design to reduce the potential for human error, provide an easy system to learn and operate, increase productivity, and reduce the ultimate investment in training. A second objective of the HECS is to enhance personnel needs for improved safety, reduced fatigue and stress, increased comfort, greater user acceptance, and increased job satisfaction.

Three interface design options are presented. Option 1 focuses on an interface that is modular and allows operation of each technology. The staffing for this interface most closely matches BWID's current plans. The operator workstations would appear identical to each other, except the software and control input device would differ.

Option 2 focuses on a more integrated interface for the BWID equipment. This option also focuses on modularity. The staffing for this option is based on operator workload and not the individual projects. The operator workstations would be identical.

Option 3 deals with the application of virtual reality. The virtual reality controls and displays could be implemented into the philosophy of either Option 1 or Option 2. This option pushes the state of the art.

A discussion on operator (user) requirements is also presented that applies to all three options. All three options would be appropriate. Since funding is not currently planned for this project during FY-95, an appendix provides information on improvements to the existing interfaces for each technology.

A review of the platform and associated engineering modifications and analysis is also given. Specifically, the platform, the equipment racks, transportation, heating, ventilating, and air conditioning, floor loadings, electrical considerations (e.g., uninterruptible power supply, generators), noise, dust seals, and a cable spool are addressed. The recommended platform for a demonstration is a single-wide trailer because it is mobile and "self-contained." Recommendations and/or discussions are given on the other associated engineering issues.

A communications system and collision avoidance system are also discussed. The communications system consists of a broadband cable that transmits data and video from the

containment building to the control station. Collision avoidance among the equipment and surroundings is also discussed. To prevent collisions, positioning system(s) must be included on all equipment.

Finally, potential problems that were identified are documented. The main issue is the current lack of integration of BWID activities. Other issues that should be addressed for the successful implementation of the BWID FY-95 demonstration are given.

In summary, conceptual designs addressing a human-engineered control station were developed and are presented. The integration of the control station would increase efficiency of buried waste retrieval, decrease cost, and improve safety.

ACKNOWLEDGMENTS

This document was authored by the HECS team. The HECS team consists of Scott Bauer, Jim Byers, Joyce Cameron, Lon Haney, Sue Hill, Reva Hyde, Gail Larsen, John Morrison, Trudy Overlin, Wendy Reece, Henry Romero, Tom Ryan, Ann Marie Smith, Stuart Walsh, and Jesse Warren.

The authors wish to acknowledge John Rawlins, the principal investigator, and Brad Griebenow, project manager and technical liaison, for their guidance in performing this work. The authors also wish to acknowledge the vendors who were contacted to gain knowledge about various equipment discussed in this document.

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ACRONYMS

ARPA	Advanced Research Projects Agency
bps	Bytes per second
BWID	Buried Waste Integrated Demonstration
CCTV	Closed circuit television
CP	Central processor
CRC	Cyclic Redundancy Check
CSMA/CD	Carrier-Sense Multiple-Access with Collision Detection
DOE	U.S. Department of Energy
EMI	Electromagnetic interference
FY	Fiscal year
HECS	Human Engineered Control Station
HVAC	Heating, ventilating, and air conditioning
INEL	Idaho National Engineering Laboratory
I/O	Input/output
ISO	International Standards Organization
LAN	Local area network
MAN	Metropolitan area network
OTD	Office of Technology Development
PBX	Private Branch Exchange
RFI	Radio frequency interference
SDA	Subsurface Disposal Area

UPS	Uninterrupted power supply
VR	Virtual reality
WAN	Wide area network

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1. INTRODUCTION

The U.S. Department of Energy's (DOE's) Office of Technology Development (OTD), Buried Waste Integrated Demonstration (BWID) Program supports the development and demonstration, testing, and evaluation of a suite of technologies that when integrated with commercially available baseline technologies form a comprehensive system for the effective and efficient remediation of buried waste throughout the DOE complex.

During fiscal year (FY) 1995, BWID will perform a field integrated demonstration of some of the technologies. The Human Engineered Control Station (HECS) was designed to support this demonstration as well as future remedial efforts at various DOE buried waste sites. The scope of the integrated demonstration is to characterize and retrieve simulated buried waste hot spots at the Cold Test Pit within the confines of a building and then to transport a portion of the simulated waste to a facility for assay and treatment.

A mobile shelter for housing the various control equipment to remediate (characterize and retrieve) buried waste was designed to support the BWID FY-95 integrated demonstration and to later support environmental restoration and remediation of various DOE sites. The HECS consists of remote control mechanisms for a gantry crane and its subsystems, an excavator, a conveyance system, and other support systems.

This project consisted of the following activities: task clarification, conceptual designs for the interfaces, conceptual designs for the platform engineering issues, concepts for a collision avoidance system, and a conceptual design for a communications network to transfer data and video from the building to the control station. The designs presented in this document support the requirements that were known during the time of design and are specific to the BWID FY-95 integrated demonstration. Currently, there is no planned funding to build this system, but it is our hope that the information contained herein will be used by future remediation activities.

1.1 Objective

The objective of the HECS is to enhance operator effectiveness and efficiency of remediation operations by providing an integrated remote control mechanism that integrates human capabilities, limitations, and expectations into the design. The HECS will reduce the potential for human error, provide an easy system to learn and operate, provide increased productivity, and reduce the ultimate investment in training. A second objective is to enhance certain desirable human values, including improved safety, reduced fatigue and stress, increased comfort, greater user acceptance, and increased job satisfaction. As a result of these considerations, integration of the individual technologies is required. Integration must occur for both hardware and software (including data transfer).

1.2 Need

The amount of buried waste located throughout the DOE complex is estimated to be approximately 3.1 million cubic meters. The majority of the waste is located at the Hanford Site, Savannah River Site, Idaho National Engineering Laboratory (INEL), Los Alamos National Laboratory, Oak Ridge National Laboratory, and Rocky Flats Plant. The wastes at these sites are buried or stored in trenches, pits, buildings, storage pads, or other structures.

Approximately half of all DOE buried waste was disposed of before 1970. At the time, disposal regulations permitted the commingling of various types of waste [i.e., transuranic, low-level radioactive waste, and hazardous]. As a result, much of the buried waste throughout the DOE complex is believed to be contaminated with both hazardous and radioactive materials. Interstitial soils are also believed to be contaminated as a result of these disposal practices, which significantly increases the volume of materials requiring remediation.

The Subsurface Disposal Area (SDA) waste pits at the INEL were excavated to the underlying basalt layer and generally backfilled with 2 to 5 ft of soil to provide a level floor. The SDA waste trenches were generally excavated to the basalt layer, approximately 10 ft down, averaged about 7 ft wide, and were up to 1,800 ft long. Following excavation, wastes were placed or dumped into the pits and trenches. From 1952 to 1963, the waste containers were stacked to optimize disposal space. During 1963 to 1969, the waste packages were randomly dumped into the pits and trenches to limit worker radiation exposure. In 1969, the waste containers were again stacked to optimize disposal volume. Once emplaced, the wastes were backfilled and covered with silty clay and sandy soil (soils native to this area).

Typical buried waste includes construction and demolition materials, laboratory equipment, process equipment, maintenance equipment, and decontamination materials. A variety of disposal containers were used and included steel drums, cardboard cartons, and wooden boxes. Larger individual items were disposed of separately as loose trash. Degradation of the waste containers is believed to have resulted in contamination of the immediate surrounding soil.

Because there are multiple DOE sites that have buried waste, it is important that the efficiency with which buried waste is characterized and retrieved is high while preserving the safety of operations. The HECS can fulfill these needs, thereby decreasing cost (through efficiency), reducing overall time to characterize and retrieve, and increasing safety (through remote operations and intuitive interfaces).

1.3 Background

Human error is a primary cause of most system breakdowns. However, most human error, or degraded human performance, is induced by some system characteristics, such as poor design, procedures, training, and organizations. By applying human factors technology, we can anticipate and avoid human error through the system design.

To develop these designs, various operating scenarios were investigated and defined. Next, the human role was defined. This included defining whether humans were operators, maintainers, sensors, managers, analyzers, decision-makers, information managers, backup to equipment, or some mix of the above.

The overall HECS consists of the technology interface stations, supporting engineering aids [e.g., heating, ventilating, and air conditioning (HVAC), racks], the platform (trailer), communications network (broadband system), and the collision avoidance system.

The HECS remote control mechanisms are for a gantry crane and its subsystems, an excavator, a conveyance system, and other support systems. The conveyance system will be automated for the FY-95 demonstration.

1.4 Operational Scenario

There are two retrieval scenarios that BWID is considering: full pit retrieval and hot spot retrieval. Both are assumed to occur within a containment building. (The following sections discuss each type of retrieval scenario that BWID is considering.)

1.4.1 Full Pit Retrieval

Site characterization would entail using electromagnetometers, magnetometers, ground penetrating radar, thermal infrared imaging, or gravity. Next, the pit area would be prepared and a building erected. Once the building is up and ventilation system installed, equipment would be mobilized to the pit for staging. This equipment could include an excavator, conveyance system, gantry crane, overburden removal end effector, monitoring equipment, dumping system, repackaging method, contamination control equipment, digface monitoring, and vacuum.

Next, the overburden would be removed from the pit. The overburden would be transported from the pit for assay using a remote conveyance system. Samples would be taken to determine if the soil is clean or has radioactive or chemical waste in it. The clean waste would be separated from the overburden waste. Contaminated overburden would be sent to a treatment facility offsite.

Finally, the entire pit would be retrieved using a remote excavator. Large objects would be sized using shears or cryogenic cutting deployed off of the gantry crane. Contamination control measures and digface characterization would be deployed by the gantry crane arms. Monitoring contamination spread would be performed. Waste would be conveyed from the digface using a remote conveyance system.

Waste would be assayed and sent offsite for treatment. All equipment would then be destaged, including the building. The pit would then be restored by putting fill dirt back into the hole(s).

1.4.2 Hot Spot Retrieval

A hot spot is an object interned in the buried waste that poses a high risk to the surrounding environment or work force. The object may present an organic hazard, a radiological hazard, or any other type of hazard that drives the risk assessment. By performing selective hot spot retrieval, the overall risk associated with a pit or trench can be reduced without going to the expense of a full-scale retrieval effort. A hot spot may be determined by a number of methods, including historical records or site characterization activities.

Once the pit has been prepared and a building is up and the ventilation system installed, equipment would be mobilized to the pit for staging. This equipment could include an excavator and/or gantry crane, a conveyance system, monitoring equipment, a repackaging method, contamination control equipment, digface monitoring, and a vacuum. Once the area of the hot spot is defined, overburden would be removed following a process similar to that followed for full-scale retrieval.

Next, hot spot retrieval would be performed in one section of the pit. Hot spot retrieval could be accomplished several different ways. There are three methods that BWID is currently considering for hot spot retrieval. The first method uses a remote excavator supported by the gantry crane for digface characterization, contamination control, and sizing. The excavator would have a removable end effector that would disconnect directly into the conveyance system, thereby reducing dust and contamination spread.

The second method of hot spot retrieval that BWID is considering uses a gantry crane with two manipulators that can work together. These arms would deploy digface characterization and retrieval end effectors to characterize and retrieve the simulated waste. In addition, the arms would deploy contamination control measures during retrieval using the Contamination Control Unit. The gantry crane would deposit the waste into a box on the conveyance system. A vacuum would also remove some dirt around objects.

The third method that BWID is considering for hot spot retrieval also uses the gantry crane but involves grouting a section of the pit, breaking up the solidified mass with an expansive alternative grout, and retrieving the broken grout using the gantry crane. Grouting the waste first provides an agglomeration of contaminants and fine soil particles that decrease the chance of contaminant spread during the inherently dusty retrieval operation. The gantry crane would deposit the waste into a box on the conveyance system.

Waste would be assayed and sent offsite for treatment. All equipment would be destaged, including the building. The pit would then be restored by putting fill dirt back into the hole(s).

1.5 HECS Team

The HECS team consisted of personnel with a broad base of educational background that contributed to the design options presented in this report. The team members and areas they supported are provided below.

Electrical, industrial, and mechanical engineering support:

Scott Bauer
Reva Hyde
Gail Larsen
John Morrison
Ann Marie Smith
Stuart Walsh
Jesse Warren

Psychology and human factors support:

Jim Byers
Joyce Cameron
Lon Haney
Sue Hill
Trudy Overlin
Wendy Reece
Henry Romero
Tom Ryan

2. QUALITY

All project activities were in accordance with the *Engineering Research and Applications Department Quality Program Plan*.[2] All activities for this project were Quality Level 2. The objective of this project was design development through the conceptual design phase. The conceptual designs are presented in this document.

An independent peer review of the HECS interface design concepts was performed to ensure that work to date had been carried out using good human factors practices to achieve a high degree of quality. The Human Factors Peer Review was performed by Dr. Alvah Bittner of Battelle Human Affairs Research Center. Bittner is a fellow of the Human Factors and Ergonomics Society and has published widely in many areas of human factors and design. He has extensive experience in the development, testing, and evaluation of complex systems. Bittner's peer review of this work is found in Appendix A.

In addition, two peer reviews for the communications system and collision avoidance system were held. In attendance were representatives from the projects affected by the systems, BWID management, Environmental Restoration, and BWID's Technical and Academic Review Group. Both peer reviews resulted in good feedback that influenced the output of these efforts (see Sections 9 and 10). All attendees expressed agreement and support of the concepts presented.

3. DESIGN AND FUNCTIONAL REQUIREMENTS

The design and functional requirements that the HECS team developed are listed below. The design options presented in this document address these requirements. Codes and standards relevant to the HECS project are given in Appendix B.

- The HECS shall provide remote control (including startup, operation, and shutdown) and monitoring of all the BWID systems planned for the FY-95 full-scale integrated demonstration. These systems include a teleoperated excavator, a teleoperated gantry crane (that will deploy contamination control, vacuum, shears, digface characterization instrumentation, and selective retrieval tools), an automated conveyance system, monitoring equipment, characterization equipment, dumping station, cameras, machine health monitoring equipment, and a supervisory controller. Access to the structure and equipment will not be allowed while equipment is operating.

- The HECS shall be able to be located at least 500 ft from the digface.

- Cabling between the equipment and the control station shall be controlled and kept to a minimum.

- The system stations shall be supplied with an industry standard network for the communication of files between the equipment operators and users.

- The design will consider general access for construction, operation, maintenance, testing, and inspection.

- This effort will consider modularity for expansion and change in outyears. High probability expansion areas include the containment structure subsystems, repackaging, size reduction, sheet piles, and alternative methods of deploying contamination control measures.

- The gantry crane must be able to deploy digface characterization, a vacuum, contamination control, and small retrieval tools. To deploy digface characterization, the gantry crane system will initiate a manually operated or preprogrammed scan sweep. A color graphics display shall present sensor data to the digface characterization geophysicist as the data are being acquired. The data may be post processed into surface plots showing the positional information with grid lines after a digface scan is complete. A color printer must be available in the control station.

- Color video cameras shall be provided to allow remote viewing of the structure and equipment. The cameras shall be supplied with pan, tilt, focus, and zoom. Lighting shall be provided as part of the structure.

- Control and acquisition system components may be calibrated individually and off-line. The components may then be reinstalled in the equipment/systems and verified for proper operation.

- The HECS shall be able to be run off of generators or line power. An uninterruptible power supply (UPS) will be required.

- The HECS shall be mobile so that it can be easily moved from one site to another.

4. BASIC PRINCIPLES UNDERLYING THE INTERFACE DESIGNS

4.1 Nature of Remote Tasks

Operating an excavator remotely is different type of task than operating an excavator while sitting in the cab. This statement reflects a basic principle underlying the interface design work. The reason that the remote task is different was succinctly stated by *Scientific American* in 1989.[3] "The task is shaped as much by human perceptual, cognitive and motor abilities as it is by engineering considerations." When looking at the teleoperation task versus in-cab operation, large differences in perception are seen. With all five senses, the operator in the cab perceives the experience of sitting in the cab of an excavator. Most importantly, the operator's vision is natural; the ability to shift focus, pan, tilt, and gauge depth is innate to the operator's vision system, requiring little cognitive effort. The teleoperator, on the other hand, is perceiving the teleoperation control area and whatever data can be transmitted from the excavation area. A human's ability to transmit such data is limited, requiring additional cognitive processing by the operator. Yet, the best remote vision does not come close to reproducing natural vision, so the difference is replaced by operator cognition. The additional processing of remote perception data places a large cognitive requirement on the remote operator that is not present for the in-cab operator. On the other hand, computerization allows the teleoperator to avoid some of the difficult motor tasks of the in-cab operator. Consider, for example, the simultaneous control in three different planes that an in-cab operator must achieve to perform the task of scraping off an even 6 in. of dirt. The operator has to control the curl of the bucket in synchronization with the boom height and stick angle. Although humans can learn to perform complex motor tasks, computers can handle such complexities and ease the burden on the operator.

The recognition that teleoperation tasks are not merely the equivalent of performing a task in a different location was a key feature in the approach to designing the interfaces. Rather than redesigning a job, the design team returned to the basic functions that the HECS must perform and proceeded forward, keeping in mind the true nature of the tasks that the work crew would have to perform.

4.2 Levels of Automation Versus Levels of Technology

Levels of automation are not synonymous with levels of technology. In fact, as shown in Figure 1, level of automation and level of technology may be viewed as the axes of a design matrix (although they are not perfectly orthogonal). As Figure 1 shows, designs can be located within such a matrix, and overall characteristics of the designs can be read off of the scales outside the axes. The scales outside of each axis represent general trends that seem to mirror movement along the axis (i.e., as a design incorporates more technology; it increases cost, decreases reliability, but increases the ability to reconfigure). These trends are general and counterexamples are easily produced (e.g., solid state components being far more reliable than vacuum tubes). However, the basic trends of these factors are useful when considering design. For instance, consider the case of trying to feed an excavator teleoperator exactly the same sensory data that an operator in the cab would have, trying to recreate the cab remotely. Such a design option would be placed

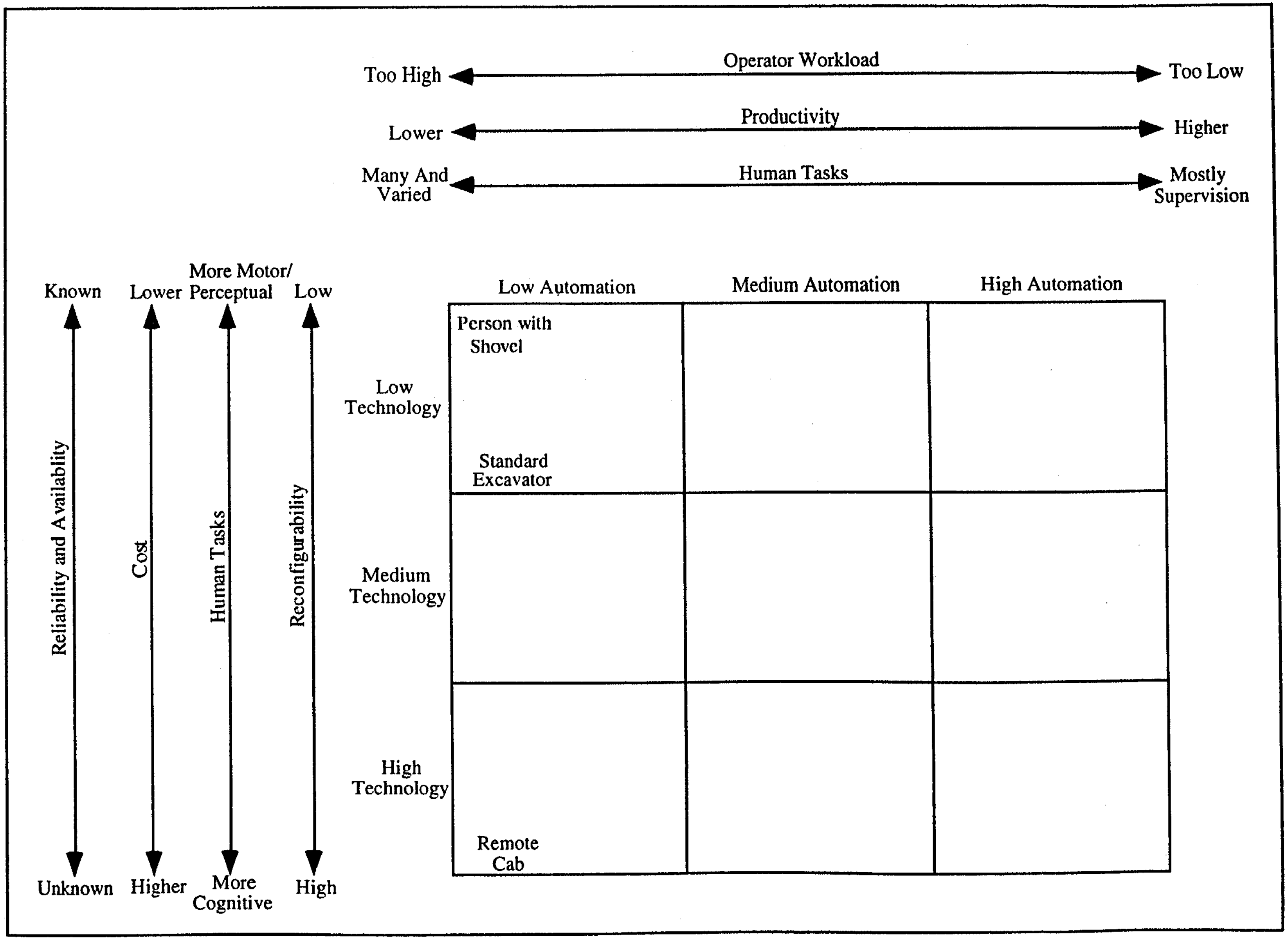

Figure 1. Automation versus technology matrix.

in the lower left hand corner of Figure 1; extremely high technology used to measure, gather, and reproduce the sensory data, but almost no automation (i.e., no human functions replaced by machine). This design would be extreme on both axes.

This leads to the HECS team's design principle of trying to avoid the extremes of the Figure 1 matrix. The HECS team avoids low automation because of the tendency toward high operator workload in complex situations and the decreased productivity, and avoids high automation because of the problem of the potential lack of situational awareness in a purely supervisory role. Low technology is avoided mainly because it does not exist in teleoperation, and high technology is avoided primarily because the risks are not yet understood. Thus, the design options are kept away from the edges of the automation-technology matrix, although some individual design elements of Option 3 in Section 6 are close to the high technology edge.

One final point about the automation-technology matrix is that designs move on the matrix with time. In particular, designs move from high technology to low technology quite rapidly, especially when dealing with computerization. The automation axis is basically stable because we can easily imagine complete automation even if we have no idea of the technology required to achieve it.

4.3 Human Factors Principles

The interface design choices were first and foremost based on sound human factors principles. A list of the most important of these principles is found in Section 3. A number of interface design options was considered. The initial screening of all the design options was based on adherence to good human factors principles.

Of particular importance in choosing the interface design options was adjustability. Adjustability is the need to accommodate individual differences among operators and to learn and improve through testing, as well as the need to accommodate future equipment changes. Accordingly, all of the interface designs presented in Section 6 make maximum use of the computer for displays and controls so that only changes to the software would need to be made to accommodate new equipment or tasks.

For controls that do involve actual positioning of end effectors, the designs attempt to reduce cognitive loading by using the principle of intuitive manipulation. That is, operators should be able to move the controls as though they were directly manipulating the end effector alone. No translation of direction would be required, as in conventional excavators or cranes, and the complexity of trying to control multiple joints would be avoided. When operators are in control using natural movement, it frees them for other tasks, such as understanding visual input.

5. HUMAN FACTORS DESIGN CRITERIA

In this section, the criteria by which the interface designs should be judged are presented. The criteria are divided into those that pertain to the human at work and those that pertain to the human's work environment.

5.1 Related to the Human at Work

A list of human factors interface design criteria considered for the human at work follows:

- Define the appropriate user population and design to meet their dimensions, capabilities, and limitations.

- Accommodate human capabilities and limitations to promote good human performance and to minimize opportunities for degraded human performance and human error.

- Ensure adequate communications links (i.e., physical, auditory, visual) between personnel and between personnel and equipment.

- Provide simultaneous access to data, controls, and displays as appropriate for communication and coordination between operators, supervisors, and strategic planners.

- Provide efficient arrangement of workplace and equipment to ensure that groupings of controls and displays reflect both frequency and criticality of use over a full range of operating conditions (i.e., normal, abnormal, and emergency operations).

- Provide consistent and compatible displays and controls that are tolerant of human error.

- Ensure that the operator who is using an automated mode of operation knows the process sequence that includes the operation just completed, the operation under way, and the operation occurring next.

- Keep workload levels appropriate for all modes of operation.

- Provide only information that is essential to task performance in high level displays, but offer the operator easy access to progressively more detailed information as desired.

- To the extent possible, replace human monitoring by computer monitoring.

- Provide alerting/warning displays to increase an operator's ability to detect conditions that may affect system performance.

5.2 Related to the Human's Work Environment

A list of human factors interface design criteria considered for the human's work environment follows:

- Provide appropriate work environment for personnel engaged in complex cognitive tasks including appropriate control of temperature, ventilation, illumination, noise, and vibration.
- Provide adequate environment for performance of task requirements under anticipated worst-case conditions (e.g., power failure).
- Consider not only operability but also maintainability.
- Ensure equipment design is compatible with clothing and protective gear worn during operation or maintenance.
- Provide adequate space for personnel, their movement, equipment, and storage.
- Provide appropriate ingress and egress, including safe and efficient stairs and walkways.

6. INTERFACE DESIGN OPTIONS

To develop the following conceptual designs, the HECS team defined functions and tasks and allocated those activities between the computer and operators. Appendix C shows the comprehensive listing of anticipated HECS functions along with a tentative identification of which BWID technology would perform each function. After this was complete, tasks for each function were described in a set of standard terms. The HECS team initially intended to describe each task by the system/subsystem it is associated with, and by what input the task requires and what output the task produces. The tasks were also to be described by a behavioral verb that describes that task action, the equipment acted upon, what causes the task to start, what feedback the task performer receives, the consequences of the task, and successful performance criteria (see Appendix D for the task description and analysis forms). This level of task description proved to be impossible for most of the BWID systems, primarily because the controls and displays were not yet finalized. However, the level of task description the HECS team was able to reach was still sufficient for the purpose of our conceptual designs. The complete list of HECS tasks is provided in Appendix E, extensively annotated with questions that still need to be answered.

The following three interface design options can accommodate a wide range of operational scenarios. The workstations can easily be modified to include new capabilities, primarily by programming. A list of functions, requirements, and interactions organized by equipment was used in producing all three designs. This listing is in Appendix F.

Because the HECS is not funded for FY-95, the HECS team felt that it was important to provide suggestions for each technology on their specific human-machine interface. These suggestions are given in Appendix G. These suggestions are given as design options based on the current equipment and software developed for the technology. These designs are by no means optimum but will improve the interface for FY-95.

6.1 Option 1

6.1.1 Operational Assumptions

Option 1 is based on several assumptions:

- Collision avoidance between various pieces of equipment (e.g., excavator, gantry crane) is preferably automated.

- Conveyance operation is not automated.

- Operation of the equipment is largely manual as opposed to automatic, although some routine operations associated with each particular piece of equipment (e.g., attaching/detaching a specific tool to one of the gantry crane manipulator arms) are automated.

- All contamination control is deployable off the gantry crane.

- Routine and preventive maintenance would occur after the normal working schedule (i.e., evening or early morning).

6.1.2 Staffing Required

The staffing suggested for this option is based on the types of equipment that must be operated as well as on the functions that need to be performed. A total of four equipment operators, one characterization team, one supervisor, and one supervisor's assistant are recommended. Each staff member has specific areas of responsibility and is expected to maintain situation awareness and to respond to warnings and alarms as needed.

1. Supervisor

   This individual will be responsible for directing all HECS operations. The supervisor will plan and coordinate strategy for waste removal/retrieval efforts and will oversee and coordinate the activities of all HECS personnel. The supervisor will also allocate equipment resources between competing activities when necessary (e.g., needing the gantry crane at two places at once). On occasion, this person will request additional information from project directors for strategic decision-making. This individual will possess the expertise needed to interpret and use all information provided by the characterization team, the operators, and the supervisor's assistant. The supervisor will maintain situation awareness of the HECS system as a whole, as well as any system it interacts with (e.g., waste handling facilities the conveyance system must interact with).

2. Supervisor's Assistant

   This individual will assist the supervisor in carrying out the supervisor's duties. The supervisor's assistant will be responsible for monitoring system status for all systems, in particular the systems for which none of the operators have responsibility (e.g., the contamination control tanks). The supervisor's assistant will also assist the characterization team as needed and will aid in programming for the gantry crane.

3. Head Gantry Crane Operator

   This individual will remotely operate the gantry crane, its manipulator arms, and all of the tools or equipment that may be deployed off of the crane or by the manipulator arms. The head gantry crane operator will receive direction from the supervisor on when, where, and how to deploy equipment. The head gantry crane operator will receive direction from the characterization team on geometries for deploying the characterization equipment. This individual will also assist the supervisor in directing the activities of the second gantry crane operator. The head gantry crane operator will also monitor system status of the gantry crane equipment.

4. Second Gantry Crane Operator

   This individual will remotely operate the gantry crane, its manipulator arms, and all of the tools or equipment that may be deployed off of the crane or by the manipulator arms.

The second gantry crane operator will receive direction from the supervisor and from the head gantry crane operator on when, where, and how to deploy equipment. The second gantry crane operator will receive direction from the characterization team on geometries for deploying the characterization equipment. The second gantry crane operator will also monitor system status of the gantry crane equipment.

5. Conveyance Operator

   This individual will remotely operate the conveyance system. The conveyance operator will receive direction from the supervisor on when, where, and how to deploy conveyance equipment. The conveyance operator will also monitor system status of the conveyance equipment.

6. Excavator Operator

   This individual will remotely operate the excavator system. The excavator operator will receive direction from the supervisor on when, where, and how to deploy excavator equipment. The excavator operator will also monitor system status of the excavator equipment.

7. Characterization Team

   This individual(s) will plan both routine and nonroutine site/digface characterization scans; inform the gantry crane operators about needed characterization deployment; consult with engineers as needed concerning the current digface and any special needs for information; analyze, interpret, and display site/digface characterization data to provide information to supplement that available through real-time survey; and communicate conclusions to the other HECS operators and others who need to know. The characterization team will also monitor system status of sensors used in the characterization process.

6.1.3 Human/System Interface Options

Each HECS staff person specified above would have a workstation. Each workstation would consist of a remote vision screen, an information screen, and a controller of a type specific to the equipment being operated (i.e., each piece of equipment would have its own controller, specifically designed for that equipment). Workstations would be identical except for controllers, and controllers could be moved from one workstation to another. The workstations would provide communications between staff with displays and data being sent between workstations.

The preferred option is to mount the remote vision screen in an adjustable upright console, and the information screen in the desk in front of remote vision screen. The controller could be placed to the right or left of the information screen on the desk. This configuration might also allow the workstation to be contained in a fold open "suitcase" for mobility/portability. An alternative option is to have the screens mounted side-by-side in an adjustable upright console with desk space and controller in front.

All control functions not allocated to the equipment-specific controller (i.e., all controls not requiring direct manual control, such as mode switches, on-off, and starting automatics) would be provided by touch controls on the information screen. Operational, control, mimic, computer model, parameter data, procedures, and communications displays would appear on the information screen in operator configurable windows. Camera view selection, pan, tilt, zoom, and focus would also be controlled from active areas on the information screen.

Specific displays would be developed for each position in the HECS. For example, the characterization team's displays would allow for display and manipulation of digface characterization data and special display development/generation, whereas the supervisor would have specialized overview and summary displays and override capabilities.

The remote vision screen would be capable of showing up to four camera views at a time in operator configurable windows. The remote vision screen would also have enhanced capabilities such as "heads up" overlay displays. Relevant cues could be overlaid on the remote vision screen for appropriate views (e.g., positioning cues) and capability for control of pointers or line drawings on the remote vision screen could be incorporated to enhance communications between staff. All information in the system would be available on any information screen. Operators would select a piece of equipment to operate and all relevant data and video would be supplied to them. They would be able to adjust the control and display windows for size and location.

Camera positions would be preselected (e.g., end effector views, spotter views, overview). The camera positioning would be easily changeable.

Real-time operation of gantry crane manipulator arms would be by direct manipulation of a controller. A shaker on the controller would alert the operator to approach of the operational limits relative to controller input. The same controller would be used for programming automatic arm motions.

Moving/driving/positioning of the excavator could be accomplished by using two separate controllers or using a dual part controller. One part of the control (or there could be two separate controllers) would control driving (e.g., joystick), and the other part of the controller would be an end effector direct manipulator (e.g., model bucket). A shaker on the controller would alert the operator to the approach of operational limits relative to controller input. Another possibility is to control excavator driving via the information screen, this would obviate any possibility of confusing the controls.

Moving/driving/positioning of the conveyance would be accomplished by selecting conveyance mounted camera position (which selects the travel direction) and using the joystick controller for movement.

6.1.4 Human/System Interface Options Listed by Equipment

Human/System Interface Options: General HECS workstation description including remote vision:

Two CRT screens (one for remote vision, one for information display). Preselected camera positions (i.e., end effector views, spotter views, overview). Controller (e.g., joystick, forceball/stick) for end effector related movements. An option is to mount remote vision CRT on a slanted upright console, and the information CRT flat (flush) in desk space in front of remote vision CRT, both directly in front of the operator. The controller could be to the right (or left) of information on the CRT on the desk. This configuration might also allow the workstation to be contained in a fold open "suitcase" for mobility/portability. This configuration may also facilitate use of a stereo vision option for remote vision CRT (e.g., if glasses are required they could be bifocal with the shutter, or other 3D technology, on the top for viewing remote vision CRT, and clear on the bottom for viewing information CRT. All display and control functions other than those delegated to the controller would be from the CRTs using touch screens. Operational, control, mimic, computer model, parameter, data, procedure, and communications displays would appear on the information screen. Windowing could be used for these displays. Camera view selection, pan, tilt, and zoom would be controlled from active areas on the flush mounted CRT (i.e., CRT touch pad with arrow type keys). The remote vision screen may have enhanced capabilities such as "heads up" overlay displays as well as pointers or line drawings for communication between operators/staff. (An alternative option is CRTs could be mounted side-by-side in slanted upright console with desk space and controller in front.)

Equipment: HECS/Human

Function/Task:

Control of remote waste retrieval equipment and related data. Communications with other operators/staff.

Interactions:

With other operators for cooperative activities. With geophysicist and supervisors.

Human/System Interface Options:

Each workstation would consist of a remote vision CRT and information CRT as described above for remote vision, and a controller of a type specific for the equipment being operated (e.g., manipulator arm, excavator). Each operator, supervisor, and geophysicist would have a workstation. For a more detailed description of the interface for each operator, see the interface option descriptions for each equipment type. Each workstation would provide remote vision as described above for the remote vision system. All control functions not allocated to the specific controller would be provided by control displays with touch areas in the information display. Each operator would have the needed information available for the tasks, through the information CRT, and relevant cues could be overlaid on the remote vision CRT for appropriate views. The workstation would also provide communications between staff. Special displays and data could be sent between workstations and capability for control of pointers, or line drawings on remote vision CRT could be incorporated to enhance communications between staff. The supervisors would have access to all operator interface options, operational monitoring capabilities, data displays, with specialized overview and summary displays, complete communications access, and override capability by using their workstations.

Equipment: Gantry Crane with Manipulators

Function/Task:

All tasks using manipulator arms, including selective retrieval, digface characterization, shoring, grouting, misting, fixants, vacuum, tools, other characterization technologies, and cryogenic cutting.

Information Requirements:

- Manipulator arm and end effector position and status (could include crane and Z mast when relevant but generally just the end effector position/status and arm motion range given the current position are primary).

- Real-time motion monitoring/tracking.

- Position and status of systems deployed by manipulator arms.

Interactions:

With other operators for cooperative activities. Receive and send displays and data to geophysicist and supervisors.

Human/System Interface Options:

Two CRT workstation as described for remote vision above. Real-time operation of arms and gripper controlled by small forceball/stick type controller keyed to end effector position. Shaker on controller would alert operator to approach of operational limits relative to controller input. Same method of arm control for teaching predetermined arm movements (e.g., standard scan patterns) using computer model as for real time. Also teaching arm by selecting points in space. Computer model could display positioning aids, such as grids or points, and coordinate values. Such aids would be part of the computer model and allow transparent overlay with remote stereo vision when desired. Relevant operational and alarm parameters and/or cues (e.g., weight, speed, direction, collision information) would be displayed in the information display and with critical cues overlaid on or near the relevant system part in the remote vision display when needed. Relevant visual and auditory cues for warnings and alarms would be available for both displays.

Equipment: Excavator

Function/Task:

Remove dirt/waste, size objects, and relocate large objects.

Information Requirements:

Excavator and bucket/shear/end effector (as well as boom and stick when needed) position and status. Real-time motion monitoring/tracking.

Interactions:

With gantry crane for cooperative activities. With geophysicist and supervisors. With conveyance system for transport.

Human/System Interface Options:

A two CRT workstation as described for remote vision above. End effector position controlled by small forceball/stick type controller (i.e., up, down, forward, back), by similar controller movement/force, and end effector movement by torque on controller "ball." Shaker on controller would alert the operator to approach of the operational limits relative to controller input to avoid lifting or tipping over excavator. Moving/driving/positioning of excavator accomplished by selecting overview camera position (or other appropriate view) and using a controller for movement. May need separate, different type, controller (i.e., joystick as in conveyance system or control from touchscreen) for excavator driving/positioning to avoid confusion with end effector movement using small forceball/stick. With some autonomy included, operator could simply tell excavator where to move by inputing position coordinates. Computer model could display positioning aids, such as grids or points, and coordinate values on information CRT and overlaid on remote vision CRT when appropriate. Relevant operational and alarm parameters and/or cues (e.g., force, torque, speed, direction, collision information) would be displayed in the information CRT and critical cues overlaid on or near the relevant system part in the remote vision CRT when needed.

Equipment: Conveyance System

Function/Task:

Receiving, transporting, and facilitation of offloading material (providing empty containers and removing loaded containers).

Information Requirements:

Conveyance and box lid position and status. Load status (material presence, clean or dirty innovative end effector piece). Required position to relocate conveyance.

Interactions:

With other operators in need of conveyance for moving material.

Human/System Interface Options:

A two CRT workstation as described for remote vision above. Joystick type controller. Moving/driving/positioning of conveyance accomplished by selecting overview camera position (or other appropriate view), and using controller for movement. Computer model could display positioning aids, such as grids or points, and coordinate values. Other operators could display desired positioning of conveyance (to conveyance operator) using position cues in overview camera view and plan view on information CRT, to facilitate their activities. Box lid would be operated using touch areas on the information CRT. Relevant operational and alarm parameters and/or cues (e.g., speed, direction, distance, load weight, status of end effector part on board, collision information) would be displayed in the information CRT, and important cues overlaid on or near the relevant system part in the remote vision CRT when needed.

Equipment: Contamination Control System Including Dust Sampling System

Function/Task:

Control contamination using misting, fixants, and grouting. Monitor dust/particulate concentration, type, and location during excavation or other dust generating activities.

Information Requirements:

System position and status for dust suppression. Sensor location/position (for dust sampling). Output data from dust monitoring system (e.g., concentration, location, type).

Interactions:

With other operators and staff for cooperative action relative to contamination control. Communicate status to relevant staff concerning dust status when it may approach levels that affect operations.

Human/System Interface Options:

A two CRT workstation as described for remote vision above. Most contamination control functions, except dust sampling and grouting, will be performed using the gantry crane with manipulator arms. Appropriate contamination control system information will be displayed to gantry crane CRT (e.g., position, flows, pressures, levels, pump/valve status) and relevant cues may be overlaid in the remote vision CRT in positions relative to the equipment. Control of system components will be accomplished by control displays with touch areas on the information CRT. End effector movement will be accomplished using the small forceball/stick type controller. (See the above general description of the use of gantry crane with manipulators for specific functions.) For the dust sampling system (not deployed by gantry crane), relevant data (e.g., dust parameters, system status parameters) from system would be displayed in the supervisor's assistant information display (could be located relative to the dust plume on an overview display) with relevant cues overlaid on the remote vision CRT in appropriate views. Control and system status information would be presented in the information CRT, with system control accomplished through touch areas in the display. Visual and auditory cues would alert operator to setpoint and alarm values/situations.

6.1.5 Pros and Cons for Option 1

Pros

- Specific controllers associated with each equipment system.
- Status quo approach to interface and work plan organization.
- Low cost option.

Cons

- Potential down-time for operators.
- Specific training needed for each equipment interface.
- Potential cognitive tunnel vision (focus on single equipment task) rather than broad mental model of entire operation.
- Low increase in efficiency.

6.2 Option 2

This option assumes some redistribution of functions (e.g., misting, and shears) from the gantry crane to other equipment. It also assumes a higher level of automation than does Option 1. These changes enable a lower staffing level, because staffing can be based on functions rather than equipment as well as increased efficiency. In terms of controls and displays, this option is not radically different from Option 1.

6.2.1 Operational Assumptions

This option is based on several assumptions:

1. Collision avoidance between various pieces of equipment (e.g., excavator, gantry crane) is automated.
2. Conveyance operation is automated.
3. Routine operations associated with each particular piece of equipment (e.g., attaching/detaching a specific tool to one of the gantry crane manipulator arms) are automated.

4. Routine misting is automated and is a distributed function with one set of misting equipment associated with the conveyance, another slaved to excavation equipment, and a third deployable off the gantry crane.

5. Objects that need to be sized would be set aside for later handling to make for more efficient operations.

6. Excavator has the capability to operate various end effectors including both the bucket and shears. Deployment of the shears off the excavator provides both more flexibility and shearing power and more equitable distribution of the human workload.

7. Spraying of fixant chemicals and foams would occur, whenever possible, after hours.

8. Routine and preventive maintenance would occur after hours.

9. Digface characterization could occur after hours.

6.2.2 Staffing Required

The staffing suggested for this option is based on the types of functions that need to be performed, rather than on the types of equipment that must be operated. A total of three equipment operators, one characterization team, and one administrative assistant are recommended, although the number could change as the actual time needed for remote performance of the many tasks associated with buried waste retrieval becomes known. Each staff member has specific areas of responsibility and is expected to maintain situation awareness, and to respond to warnings and alarms as needed.

1. Chief Operator

   This individual will be responsible for directing the removal/retrieval operations. He/she will operate the excavation and vacuum equipment used for removal/retrieval of buried waste, will monitor the routine misting associated with these tasks, and will allocate equipment resources between competing activities when necessary (e.g., needing the gantry crane at two places at once). On occasion, this person will probably request additional information for strategic decision-making (e.g., the need for additional information about the estimated size and/or content of a still partially buried object, the need to employ additional contamination control measures, the need for special camera views, etc.). This individual will also possess the expertise needed to interpret and use information provided by the characterization team, contamination control expert, and environment monitor. At times, this individual may leave the excavating task to operate shears.

2. Operator

   The operator will work with the chief operator like a co-pilot in a airplane—two people engaged cooperatively in the accomplishing a single complex task. This individual will be responsible for planning and coordinating contamination control efforts including monitoring environmental sensors (especially for signs indicating the need for a change in removal/retrieval strategy) and operating contamination control equipment above and beyond the automated routine misting. This individual may also identify nonroutine needs for information, operate remote cameras when special views are required, and assist the chief operator in other nonroutine tasks that may occur.

3. Assistant Head of Characterization Team

   This individual will operate site/digface characterization equipment, will monitor quality of incoming data, will consult with characterization team and/or head of the characterization team to ensure selection of characterization technology matches information needs, and will consult with characterization team and/or engineers when nonroutine scans for information are needed. He/she will also select and adjust camera views needed to operate site/digface characterization equipment.

4. Head of Characterization Team

   This individual(s) will plan both routine and nonroutine site/digface characterization scans; will guide the activities of the assistant to the characterization team; will consult with engineers as needed concerning the current digface and any special needs for information; will analyze, interpret, and display site/digface characterization data to provide information to supplement that available through real-time survey; and will communicate conclusions to HECS operators and others who need to know.

5. Environment Monitor/Administrative Assistant

   This individual is responsible for routine activities such as general monitoring of total system status and maintaining maintenance schedules. The environment monitor/administrative assistant will alert appropriate individual(s) as system status requires.

6.2.3 Human/System Interface Options

The basic human system interface would be accessed through a large computer screen (e.g., a 21 in. or larger monitor). The face of the monitor would be divided to provide four types of information:

1. Operational information (e.g., menus to issue commands to equipment, pop-up dialogue boxes for command confirmation, integrated displays for systems relative to operator's responsibilities).

2. Overview of entire dig site to help operators maintain situational awareness of where the various pieces of equipment are located. This window of information could show a camera overview or a computer updated schematic showing equipment location. Computer enhancement of video views could be used (e.g., it might be possible for an operator to superimpose the schematic on the camera view if scale and orientation were appropriately controlled).

3. Camera views to aid in confirmation that automated tasks have been completed and to aid in manual operation of equipment that requires positioning. Incorporates tilt/pan/zoom/focus controls.

4. Warning and system status display that would indicate systems with developing problems. Specific menus of information to diagnose the nature of the problem could be accessed from this area of the screen.

The window housing warning information would be fixed in location, but other windows could be sized and located according to the task in progress (e.g., when using automatic operation of equipment the site overview might be most useful; when positioning a piece of equipment manually the camera views window might be most useful). A reset control would be available to restore the screen to a standard configuration automatically if necessary.

Human interaction with the screen could take place using a variety of input devices including mouse, trackball, joystick, keyboard, or voice. Dimensions of the screen would make touch-screen access to some areas impractical for workers of short stature. Additional control devices associated with the manual operation of equipment would also be available (e.g., joystick, yoke, trackball, voice) for positioning equipment. Control devices would be provided with a connectivity/lockout device to ensure that only one operator can operate a specific piece of equipment at any one time.

Wickens[4] recommends the use of integrated displays as one strategy to aid operators in maintaining an accurate mental model of an evolving situation. It would seem that at least two types of information associated with BWID operations could be displayed in an integrated fashion: (a) information derived from sensors related to environmental quality and contamination control and (b) information derived from equipment sensors related to system status. Information derived from these sensors is recorded using a variety of conventional unit(s) of measurement, many of which are highly specialized. Interpretation of each of these bits of information in terms of whether it indicates that all is well, that some element is nearing acceptable limits, that some element has exceeded operational limits, or even that some element is below acceptable limits could require extensive knowledge. Use of an integrated display that gives the operator an initial overview of system status and that allows the operator access to additional data, and perhaps even aid in interpretation of that data, could help to increase situation awareness and to decrease operator workload. It could allow individuals with supervisory responsibilities to anticipate some problems before reaching a state that would have serious consequences in terms of time, money, and system safety.

6.2.4 Human/System Interface Options Listed By Equipment

Equipment: HECS

- Work area of appropriate shape and dimensions for use with chosen control options.
- Ergonomically adjustable chair of a design that is compatible with chosen control options.
- Individual large screen monitor that can be split into windows to display different types of information.

- Small area in standard, unmovable location (e.g., upper right hand corner) would be dedicated to warnings and integrated system status displays.

- Other windows would be dedicated to "big-picture" video views, camera views, equipment operations (menus, commands, etc.), and detailed data displays. These windows could be sized and placed according to operator tasks and preferences.

- A reset button could be made available that would put the standard windows (e.g., warnings and system status, big picture video, camera views, and operations) into a standard designated configuration automatically in case of emergency.

- Special configurable window(s) would be available for other uses (e.g., characterization team's data analysis, administrative assistant's scheduling software).

• Possible generic hardware to enable operator to interact with screen displays

  - Trackball

  - Keyboard

  - Joystick

  - Miniature headset for voice commands

  - Touch screen

  - Touch pad

  - Mouse

  - Kinematic controller.

• Possible generic hardware for control of equipment—choice would be dependent on the amount of automation involved in the operation of a particular piece of equipment. Choices could range from complete automation where the operator would simply issue a command and monitor its results, to teleoperation with manual control of a particular end effector. Intermediate allocation of functions between manual and automated control are also possible (e.g., manual placement of excavator bucket in space with automatic "distancing" to make contact between bucket and surface prior to "scooping.")

  - Large (full hand grip, not just finger grip) joystick for teleoperation of excavator and/or gantry crane end effectors and camera tilt/pan/zoom/focus functions. A joystick could be made to issue a warning by vibrating (stick-shaker joystick) when a piece of equipment is operated in a manner that is approaching operational parameters. A freeze mode could also be provided that would interrupt operation of a piece of equipment if it was being operated in a manner that was close to exceeding operational parameters (e.g., the operator response to a warning did not ensure that a predictable error such as tipping an excavator due to exertion of too much force did not occur).

- Trackball

- Kinematic controller for end effector location where operator would physically manipulate representation of end effector in space.

- Keyboard input

- Voice input

- Lever

- Slide

- Touch pad

- Control "yoke" (similar to the one used to control an experimental helicopter) that could provide direct control of motions in 3D space. A control yoke could be equipped with a "stick-shaker" vibrational warning system that would be activated whenever a piece of equipment is operated in a manner that is approaching operational parameters. A freeze mode could also be provided that would interrupt operation of a piece of equipment if it was being operated in a manner that was close to exceeding operational parameters (e.g., the operator response to a warning did not ensure that a predictable error such as tipping an excavator due to exertion of too much force did not occur).

• Some cameras would be slaved to end effectors so that under normal operating conditions there should not be a need to operate an end effector and position a unique camera view at the same time.

• Work space design would be dependent upon chosen control options. Work space for operators could be identical with access to specific cameras or pieces of equipment requiring steps to ensure that two people do not try to operate the same item at the same time. Work space for the administrative assistant might need to be of a different design.

• Shared computer generated and updated schematic of containment building floor plan that could also be viewed on individual operator monitors with operator selected overlays (e.g., collision avoidance bubbles).

Equipment: Remote Vision System

- Several strategies for camera mounting would be needed to provide a variety of camera views. Possibilities include

  - Mounted high in containment building to provide "bird's eye view" of interior of building (fixed mounting with and without tilt/pan/zoom/focus functions available).

  - Mounted in fixed positions with tilt/pan/zoom/focus functions to provide "spotter views."

  - Mounted on fixed equipment (e.g., tool storage area) with tilt/pan/zoom/focus views available.

  - Mounted on moveable equipment with tilt/pan/zoom/focus functions.

  - Mounted on equipment or in fixed locations and slaved to end effectors.

  - Deployed on gantry crane manipulator arm with tilt/pan/zoom/focus functions available for special views.

- Several different strategies for positioning cameras for specific views could be used. Choices should include options that provide operator with control over some "big-picture" views, "spotter" views, and "close-up" views. At least one "big-picture" camera should be immovable to provide a constant reference. Operator selection of the camera to be adjusted using tilt/pan/zoom/focus functions should require steps that ensure that one operator does not move a camera that another is using. Possibilities for controlling camera positioning functions could include

  - Stick-shaker joystick

  - Stick-shaker yoke

  - Trackball

  - Slide or level controls

  - Push button controls

  - Touch screen/pad

  - Mouse

  - Keyboard

  - Automated computer commands

- Voice command.

- Possible strategies for displaying camera video images include

  - Direct camera video images

  - 2D camera video enhanced by computer generated overlays to aid in depth perception or to provide other types of information to aid the operator (e.g., grid to help estimate dimensions and envelope for safe operation)

  - 3D video

  - 3D video enhanced by computer generated overlays to aid the operator (e.g., grid to help estimate dimensions and envelope for safe operation)

- Shared computer generated and updated schematic of containment building floor plan that could also be viewed on individual operator monitors with overlays (e.g., collision avoidance bubbles).

Equipment: Gantry Crane

- The two specific design options described below are based on the assumption that routine, repetitive gantry crane tasks (e.g., attach/detach a particular tool, move gantry crane superstructure to a specific location, follow a predetermined scanning pattern during site/digface characterization) are automated so that the operator can issue a command and monitor task performance rather than engage in teleoperation of equipment in the remote environment.

- Commands for automated gantry crane operations could be issued in a variety of ways, including

  - Keyboard input

  - Menu selection (with cursor control via keyboard, trackball, mouse, joystick, or voice command)

  - Icon dragging.

  Consistency of command structure and input format between various gantry crane operations and between operations associated with each of the various pieces of equipment within the containment building would be important in the design selection process.

- Selection of control operations for the manipulation of gantry crane end effectors would depend, in part, on the movement patterns required by a particular end effector (e.g., regular and predictable, irregular and unpredictable, located in a plane, or located in 3D space), and some could be easily automated.

- Teleoperation of activities that could not be easily automated include

  - Teleoperation of end effector in video environment (i.e., 2D, enhanced 2D, 3D, enhanced 3D) using stick-shaker joystick in the dominant hand to control 2D motion. Motion in a third dimension, operation of on/off controls, and operation of pressure/flow controls would require additional control resources such as lever/slide/push button/knob/computer display/touch screen/touch pad/voice command operated in conjunction with the joystick. It might be possible to arrange these resources for operation by the nondominant hand, voice control, or additional options on the basic joystick unit. Additional information about the movement characteristics and control demands of a particular end effector would be needed to determine the best option for a particular need.

  - Teleoperation of the end effector in the video environment (i.e., 2D, enhanced 2D, 3D, enhanced 3D) using a stick-shaker yoke with both hands to control 3D motion (i.e., left/right, in/out, and up/down). Additional control resources (e.g., voice input of standardized commands) might be needed in conjunction with the movement of the yoke to manipulate some end effectors.

Equipment: Excavator

One goal of this design option is to provide the operator with a consistent set of control movements to control objects in 3D space. That is, it is hoped that a single set of controls could be used to position and manipulate the excavator end effector, gantry crane end effector, and camera. The design could include

- Teleoperation of excavator end effector in a video environment using a stick shaker yoke that would provide controllable motion in three dimensions. Additional control parameters could be placed under voice control. Selection of this control option would have a profound impact on the design of operator work areas that might be thought of as sort of a "cockpit" configuration rather than a desktop configuration.

- Teleoperation of excavator end effector in a video environment using a stick shaker joystick option.

- Kinematic controller option

- Automated option

- Mixed option.

Equipment: Conveyance

Essential to the philosophy of these design options is the intent to automate routine operations and ideally the majority, if not all, of the conveyance operations, including

- Movement to a particular area within the contamination building, whether to provide an empty waste container, pick up a load of waste, or to transport a load of waste to a staging area for further processing.

- Opening the lid of the box upon arrival at the location for receiving a new load of waste.

- Detecting when a box is "full," whether due to depositing a full end effector from the excavator or from some other type of load.

- Closing the lid of the box when it is full.

- Exchanging a full excavator end effector for an empty one.

Commands to perform, or monitor, each of these tasks could be issued using a variety of input devices including keyboard input, menu selection (with cursor control via keyboard, trackball, mouse, joystick, voice command), and/or dragging an icon.

In addition, contamination control (misting) of the path used by the moving conveyance could be slaved to the conveyance itself. Dust sensors could be attached to the conveyance itself to record the dust plume following its movements. If the dust plume was above a designated concentration, misting from a self-mounted tank containing dust suppressants could be initiated on the next trip to or from the staging area.

Normal operation of the conveyance sensor data could activate a freeze feature to stop the conveyance in its tracks in case of impending collision, or in case of dangerous operations such as operating too close to the edge of the pit. Operators should be involved in selection and/or confirmation of remedial actions such as "back up from the edge using the path you just took" that might be recommended by an automated system.

Teleoperation of the conveyance might be needed in dire situations. Options are difficult to generate without knowledge about the amount of automation employed and fail-safe options built into the automated performance of the conveyance.

6.2.5 Pros and Cons of Option 2

Pros:

- Deployment of human operators in terms of the functions to be achieved, rather than in terms of the equipment to be operated, should
  - Contribute to situational awareness
  - Result in better use of the human's time (i.e., less wait time without a specific task to perform)
  - Require fewer human operators.

- Automation of routine operations and monitoring tasks should enhance human performance.

- Use of consistent movements and commands to control excavator, manipulator arms, and cameras could reduce training time and enable operators to assist one another if necessary.

- Use of integrated displays where possible should reduce operator workload. Easy access to more detailed information if needed should enable operators to diagnose and resolve problems as needed.

- Automation based on software rather than hard-wiring is flexible and relatively readily changed if the situation demands.

Cons:

- Remote control of heavy equipment is not traditional and may require some time/training for operator acceptance.

- Reliance on newly developed software for automated functions can require time to work out all of the bugs.

- Use of stick-shaker controls to provide warning feedback may require some research and development to determine movement pattern stereotypes and appropriate sensor settings.

- Possible negative transfer due to universal controller. Negative transfer refers to the transfer of learned behavior from one task to another when that behavior is undesirable in the second task. Negative transfer results in reduced performance.

6.3 Option 3

6.3.1 Operational Assumption

This option will support a wide range of automation. This range consists of a continuum from manual teleoperation of all system parts to total automation with the operator having only monitoring and override/stop functions. Given current philosophy and technology for automation, the level of automation would likely fall somewhere between these two extremes.

6.3.2 Staffing Requirements

This option will support any staffing configuration that meets adequate human engineering requirements. Staffing could be organized by equipment or by function (see Option 1 for staffing by equipment and Option 2 for staffing by function). This option will support division of tasks and responsibilities as needed. This includes operational, supervisory, scientific specialization (i.e., characterization team), technical specialization, emergency, assistant, advisory, and other staffing types as needed. Staffing could be as little as a single operator for highly automated operation to as many as are needed for a given function and responsibility.

6.3.3 Glossary

The terms provided in this section apply to Option 3.

3D auditory—The characteristic of a hearer being able to locate the position of a sound source (or apparent sound source) in relation to the position of the hearer by using the sound from the source (or apparent source).

Augmented telepresence—The use of hardware, software, and telemetry presenting stimuli to a user's senses similar to how it would be received if they were present at a particular remote location. The presentation to the user could be augmented with computer generated and/or enhanced characteristics and "heads up" type displays.

Data glove—A type of computer input device consisting of a light glove with fiber optic position sensors for finger and thumb position.

Exoskeleton—A device attached externally to the user's body, articulated to allow user movement, to be used as a computer input device and/or provide haptic displays to the user.

Flying mouse—A computer input device analogous to a typical computer mouse only with tracking in the z as well as the x and y axes.

Ghost conveyance, (or other ghost equipment/component)—A representation (semitransparent, or stick figure) of the conveyance (or other component or equipment) in the augmented telepresence environment. The representation could be positioned by a user/operator for purpose of commanding/controlling movement of the conveyance (or other equipment) or for communicating positioning needs to another user/operator.

Haptic display—A display that presents tactile and force feedback type stimuli to a user.

Hover disk mounted stereo camera system—Remote stereo vision system with cameras mounted on a fan powered flying disk. Cameras and positioning/flying of the disk would be under the control of the user.

Piccolo—A computer input device shaped to fit the hand and having many buttons or activation points. Analogous to the throttle and joystick of an F-16 fighter jet (i.e., playing the piccolo in a dogfight) only may be free from direct attachments (except possibly a wire) to any surface as is the flying mouse.

Real 3D widget—A computer input device that exists in the real world, designed to allow for interaction in a 3D environment (see flying mouse, wand, and piccolo).

Remote hearing/superhearing—Augmenting user hearing by the use of remote microphones.

Stereo vision—A display presenting differing images to each eye of the user to provide a sense of visual depth.

Virtual 3D widget—A computer input device that exists only in cyberspace, designed to allow for interaction in a 3D environment (see flying mouse, wand, and piccolo).

Virtual reality (VR) helmet or eyephones—A head mounted device for presenting visual and auditory information to the user. The device can present a separate image to each eye of the user to facilitate presentation of a 3D visual image. An audio speaker is provided for each ear of the user with the capability of presenting discrete audio to each ear. The device may also incorporate a mechanism for tracking head position.

Wand—An input device in the form of a wand (e.g., long, slender, cylindrical, possibly tapered) designed for interaction in a 3D environment.

6.3.4 Human/System Interface Options

Each workstation would consist of a VR helmet or eyephones and data glove. Each operator, supervisor, and characterization team would have a workstation. Each workstation would provide augmented telepresence as described below for the remote vision system. Each operator would have available the needed information for their task, able to be displayed in the VR augmented telepresence environment provided by the workstation. The environment would also provide for control of needed equipment and for communications with other staff. For a more detailed description of the interface for each operator, see the interface option descriptions for each equipment type. The supervisors (using the VR augmented telepresence environment) would have access to all operator interface options, operational monitoring capabilities, data displays, and specialized overview and summary displays, complete communications access, and override capability by using their workstations. Most interactions occur in the augmented telepresence virtual environment.

6.3.5 Human/System Interface Options Listed by Equipment

Equipment: Remote Vision System

1. VR helmet or eyephones. Data glove. Wide field stereo vision. Preselected camera positions (i.e., end effector views, spotter views, overview). Overlay of 3D computer model onto remote vision (e.g., transparent model or salient edge cues, vision/model mixing under user control on continuum or discrete steps). Head tracking for pan and tilt. Movement/scale control for zoom and camera position selection (e.g., using voice, gesture or virtual 3D widget such as wand or flying mouse). Alarms, operational parameters, and collision envelopes or bubbles could also be overlaid on stereo vision when needed. 3D auditory (mikes at camera positions, enhanced super hearing for other relevant auditory thus presenting system sounds not necessarily picked up by camera mikes).

2. VR helmet or eyephones. 3D widget. Same as alternative 1, however, with real 3D widget instead of data glove and virtual widgets. Widget may be in form of flying mouse, piccolo, or wand. Voice control could minimize or eliminate buttons.

3. Same as alternatives 1 or 2 but with hover disk mounted stereo camera system under user control to augment preset camera positions. Would be selected by user as are other views,

and then controlled for unlimited positioning outside collision positions. May eliminate need for some or all preselected spotter camera positions (preselected end effector camera positions should remain).

Equipment: Gantry Crane with Manipulators

1. VR helmet or eyephones. Data glove. Augmented telepresence as described above for remote vision system. Real-time operation of arms and gripper controlled by operator arm movement, hand gestures, and voice command (e.g., operator speaks "grip rotate clockwise 135 degrees"). Articulated counterbalanced support for operator's arm could be provided to reduce physical stress. Same method of arm control for teaching predetermined arm movements (e.g., standard scan patterns) using VR/computer model as for real time. Also teaching arm by selecting points in space by pointing and/or using voice commands for position coordinates. VR model could display positioning aids, such as grids or points, and coordinate values. Such aids would be part of the computer model and allow transparent overlay with remote stereo vision when desired. Relevant operational and alarm parameters and/or cues (e.g., weight, speed, direction, collision information) would be displayed in the augmented telepresence display overlaid on, or near, the relevant system part when needed. Relevant computer generated 3D auditory cues (e.g., warnings, alarms) could be presented in addition to the remote hearing/superhearing.

2. VR helmet or eyephones. Exoskeleton for operator's hand/arm, or data glove and exoskeleton for operators' hand/arm. Similar to alternative 1, however, exoskeleton would provide force feedback (haptic display) to the operator of relevant forces experienced by the manipulator arm. Exoskeleton could also replace data glove as input device.

3. Similar to alternative 1 above. In addition, specific methods of display of relevant information for each application would be developed. Also specific methods of control relevant to the particular application would be developed. For example, the characterization teams workstation would allow for display and manipulation of digface characterization data in three dimensions, special display development/generation (by the characterization team) and the ability to transmit data and displays to other staff. Control and display will occur in the VR augmented telepresence environment. Exoskeleton could be incorporated for relevant force feedback if such feedback facilitates operator performance.

Equipment: Excavator

1. VR helmet or eyephones. Data glove. Augmented telepresence as described above for remote vision system. Operation by operator arm movement, hand gesture, and voice. Moving/driving/positioning of excavator accomplished by selecting overview telepresence camera position (or other appropriate view), gripping excavator with hand (in VR augmented telepresence environment) and moving the excavator, or by tracing the desired path with finger and controlling movement/speed by voice, gesture, or virtual 3D widget. With some autonomy included, operator could simply tell excavator where to move by pointing and/or voice commands. Control of end effector position and status controlled by moving and positioning hand (e.g., hand becomes bucket; thumb and index/forefinger

become shear), or use of a virtual 3D widget. VR/computer model could display positioning aids, such as grids or points, and coordinate values. Such aids would be part of the computer model and allow transparent overlay with remote stereo vision when desired. Relevant operational and alarm parameters and/or cues (e.g., force, torque, speed, direction, collision information) would be displayed in the augmented telepresence display overlaid on, or near, the relevant system part when needed. Relevant computer generated 3D auditory cues (e.g., warnings, alarms) could be presented in addition to the remote hearing/superhearing. Articulated counterbalanced support for operator's arm could be provided to reduce physical stress.

2. VR helmet or eyephones. Exoskeleton for operator's hand/arm, or data glove and exoskeleton for operator's hand/arm. Similar to alternative 1, however, exoskeleton would provide force feedback (haptic display) to the operator of relevant forces experienced by the excavator, bucket/end effector/shear. Exoskeleton could also replace data glove as input device.

Equipment: Conveyance System

1. VR helmet or eyephones. Data glove. Augmented telepresence as described above for remote vision system. Operation by operator arm movement, hand gesture, and voice. Moving/driving/positioning of conveyance accomplished by selecting overview telepresence camera position (or other appropriate view), gripping conveyance with hand (in VR augmented telepresence environment) and moving the conveyance, or by tracing the desired path with finger and controlling movement/speed by voice, gesture, or virtual 3D widget. With some autonomy included operator could just tell conveyance where to move by pointing and/or voice commands. Box lid operated by touch/interaction, gesture, or voice command. VR/computer model could display positioning aids, such as grids or points, and coordinate values. Such aids would be part of the computer model and allow transparent overlay onto remote stereo vision when desired. Other operators could display desired positioning of conveyance (to conveyance operator) using "ghost conveyance" or position cues, to facilitate their activities. Relevant operational and alarm parameters and/or cues (e.g., speed, direction, distance, load weight, collision information) would be displayed in the augmented telepresence display overlaid on or near the relevant system part when needed. Relevant computer generated 3D auditory cues (e.g., warnings, alarms) could be presented in addition to the remote hearing/superhearing. Articulated counterbalanced support for operator's arm could be provided to reduce physical stress.

Equipment: Contamination Control System Including Dust Sampling System

1. VR helmet or eyephones. Data glove. Most contamination control functions, except dust sampling, will be performed using the gantry crane with manipulator arms. Appropriate contamination control system information will be displayed in the augmented telepresence environment (e.g., position, flows, pressures, levels, pump/valve status etc.) in positions relative to the equipment. Control of system components will be accomplished by interactive touch, gesture, and/or voice command in the augmented telepresence environment. (See the above general description of the use of gantry crane with manipulators for specific functions.) For the dust sampling system, (not deployed by gantry

crane) relevant data (e.g., dust parameters, system status parameters) from the system would be displayed in the augmented telepresence environment in locations relative to the dust plume. Control of dust sampling system would be accomplished by interactive touch, gesture, and/or voice command. Control and system status information would be presented in the augmented telepresence environment in meaningful locations relative to the equipment or dust plume. Visual and auditory cues would alert operator to setpoint and alarm values/situations.

6.3.6 Pros and Cons of Option 3

Pros:

- Potential for reduced cognitive complexity and increased situation awareness as compared to more traditional analog or 2D screen based interfaces. This potential exists due to the possibility of designing an interface in which the user interacts with the system in a "natural" manner (e.g., 3D vision, 3D hearing, touching, talking), requiring reduced perceptual demand, less cognitive integration of information from multiple displays, and a more direct and intuitive means of control of equipment.

- Potential for optimization of human performance and reliability (including reduced opportunity and probability for error) due to reduced cognitive complexity, increased situation awareness, and intuitive control.

Cons:

- Some level of human factors research is required to determine how best to implement augmented telepresence in terms of human performance and reliability. Research issues include methods of representation for telepresence and augmentation displays, methods of interaction, and physical and emotional response to the environment.

- Some hardware and software would require development specific to the application. (Although many parts may be obtained commercially, an adequate system could not be acquired off-the-shelf for this application).

6.4 Discussion of Options

Three interface design options were presented. All three options can accommodate a wide range of operational scenarios and offer flexibility for modularity and future expansion. All three designs meet the requirements that were established.

Option 1 most closely fits BWID's current plan in that each technology has its own staff and workstation(s). Option 1 also allows staff to trade between workstations, just moving a controller and choosing a different software screen. The communications network (via a broadband—see Section 9) supports accessing data and video needed from any station.

Option 2 is the preferred option from a HECS team perspective. Option 2 takes the operators into account and attempts to distribute responsibilities based on tasks (not equipment) and workload.

This option forces integration of activities by breaking down the barriers around each separately funded technology.

Option 3 offers more research and development for controlling equipment. Really, the virtual reality concepts discussed could be implemented into either Option 1 or Option 2 philosophy. This option may more closely match BWID's mission of developing new, innovative technology.

All three options were presented because each of them meets the requirements and each offers different advantages. Any one of the options would allow for expansion and modularity.

7. USER DEFINITION

While information at this point is still too sketchy to completely specify all the HECS operators' requirements, it is useful to make some general comments here about what kinds of characteristics the HECS operators will need. Although training for HECS operators should include instruction on the mechanics of the BWID machinery and "real life" exposure to the operations of the BWID equipment, the biggest requirements on the operators will be that they are able to process the information received remotely, make decisions based on this information, and utilize the interface/controls to accomplish the task. Human operators for the above options would possess the following characteristics:

- Possessing the expertise (knowledge, skill, and judgment) necessary to plan strategy and make decisions needed to engage in remote retrieval of waste
- Technically competent (knowledgeable about the use of computers and automated systems, knowledgeable about the kinds of hazards found in the containment environment, skilled in using a computer, familiar with teleoperation of equipment)
- Capable of working independently and cooperatively with others to accomplish a larger task
- Normal vision and hearing
- Capable of clear speech and a minimum required level of hand-eye coordination and dexterity for at least one arm/hand

Some of the above characteristics can be accomplished via training, and additional training would undoubtedly be associated with preparing operators for individual HECS positions.

8. OTHER ENGINEERING CONSIDERATIONS

There are other important engineering considerations regarding the control station. These include the platform (e.g., trailer, building), equipment racks, transportation precautions, HVAC, floor loadings, uninterruptible power supply, generators, power distribution, noise considerations, dust seals, and a cable spool. Each of these considerations is discussed below.

8.1 Platform

The platform refers to the housing for the control station (e.g., trailer, building). Section 8.1.1 discusses the platform options. Section 8.1.2 discusses the recommended platform for the FY-95 BWID integrated demonstration. Section 8.1.3 discusses the expansion options for the suggested platform.

8.1.1 Options

Several alternatives were considered for the HECS platform. The primary alternatives considered were a permanent building, modular building, double-wide trailer, and single-wide trailer. The single-wide trailer option was selected for this design. A summary of the pros and cons of each option is provided below:

- Permanent Building—Although a permanent building provides a custom workspace for the HECS that is easily upgraded to meet future needs and can be designed to easily withstand the elements, the lack of mobility, need for special funding, and the overall costs outweighed these advantages.

- Modular Building—Modular buildings provide a clear advantage in that they are extremely modular and expandable and can be designed exactly to meet project requirements. The buildings themselves are not particularly mobile but can be moved if the need arises with additional installation costs at the new location. Modular buildings may be lower cost than permanent buildings but do not provide advantages in mobility or overall cost.

- Double-Wide Trailer—This option provides the advantage of added space over the single-wide trailer option. It is a mobile platform and provides room for future expansion. However, the added cost, added complexity to HVAC and wiring systems (due to the need to separate the two halves for moving), and the need for dust sealing of the two halves for moving outweigh these advantages.

- Single-Wide Trailer—This platform offers a low cost, mobile platform that provides adequate space for the current HECS requirements. The control area will be sealed off (air) from the conference room and bathroom and main door to reduce noise and dust in the control area. To accommodate visitor viewing while reducing the glare for the control room, the wall between the conference and control areas will be made of smoke colored plexiglass. A door with dust seals will be located to allow access (emergency exit and restroom access) from the control area to the conference room. Another method to accommodate visitors will be to add a walkway (deck) outside of the geophysicist's room bay window. Modifications to the floor plan and HVAC system are simple and easy to implement. The primary disadvantage of this alternative is the lack of space for future expansion. Several options for addressing this issue are discussed in Section 8.1.3, Expansion Options. Additional details about this option are included in Section 8.1.2.

A summary of the options is presented in Table 1. The various platforms were ranked with respect to each other based on mobility, cost, and expendability. A "1" is considered the best.

8.1.2 Selected Platform

To accommodate all of the operational and visitor requirements, the single-wide trailer will be divided into three primary sections. First, a conference room is provided for tours, meetings, and demonstration videos. Secondly, a HECS control room and geophysics room provide a noise reduced, interruption free work area for the equipment operators. A plexiglass viewing wall is provided to allow visitors to view the equipment operation from the main hallway. Lastly, an equipment room with a separate HVAC system is provided to house the electrical equipment.

The original floor plan for the selected trailer (Guerdon Model 47611)[5] is shown in Figure 2. To accommodate the various functions of the HECS, the floor plan would require some modifications. The modified floor plan is shown in Figure 3. The primary changes to the floor plan include

- One bedroom will be removed and the space incorporated into the main living area, which will become the HECS control room
- The central bathroom will become the equipment room
- The dryer alcove will have doors added to provide a dust and noise reducing chamber for the UPS
- A plexiglass wall (with a door in it) will be added between the main entry and the HECS control room
- The door in the master bedroom closet will be moved and the closet will become an equipment storage room (for personal protective equipment, etc.).

Table 1. Summary of platform options.

Platform	Mobility	Cost	Expendability	Comments
Permanent building	4	4	1	Best suited for long-term use
Modular building	3	2	2	Quick to fabricate
Double-wide trailer	2	3	3	Expandable and mobile
Single-wide trailer	1	1	4	Most mobile and least expensive

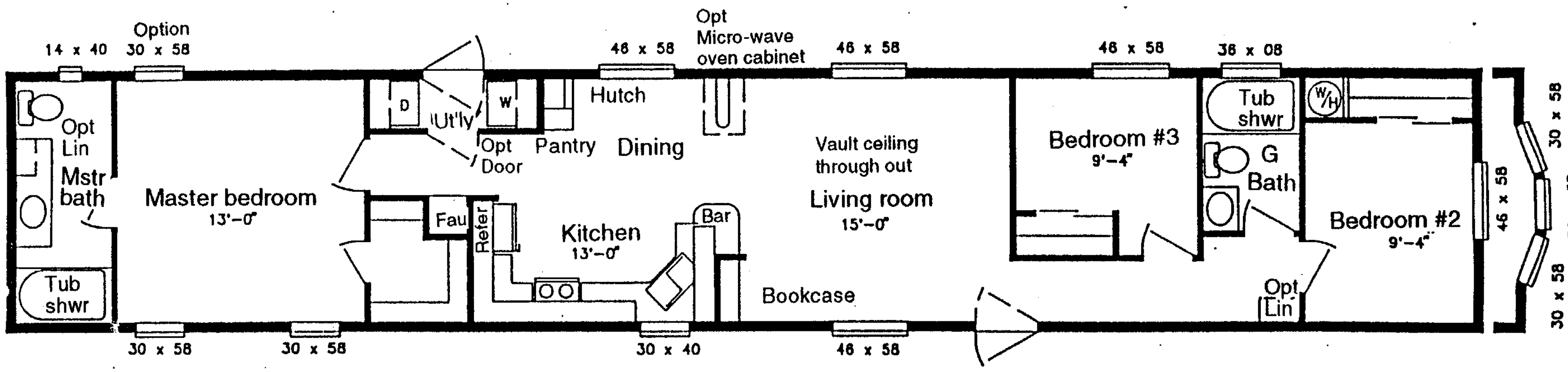

Figure 2. Original floor plan for single-wide trailer (Guerdon Model 47611).[5]

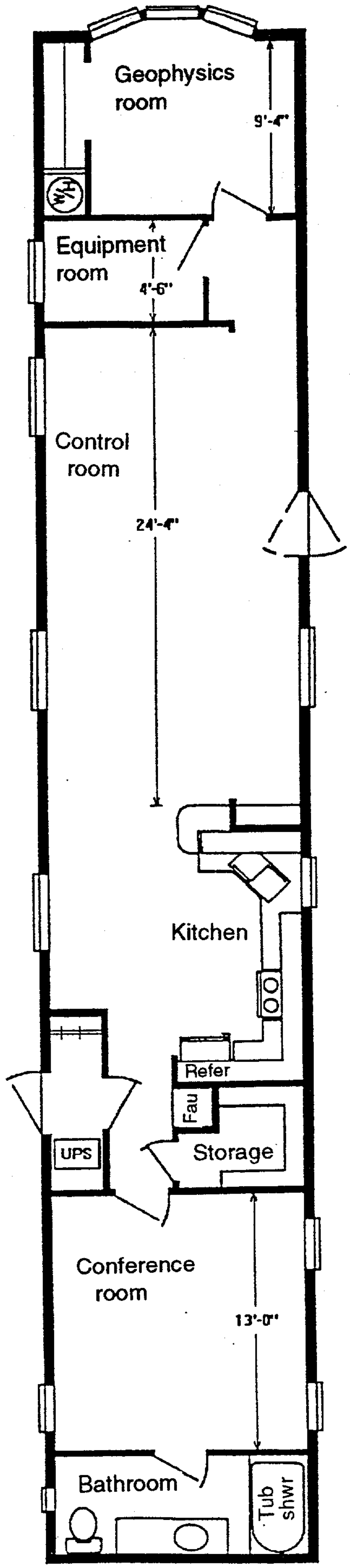

Figure 3. Modified single-wide trailer for the HECS.

These changes provide for three separate work areas within the HECS trailer that meet all of the operational and visitor requirements. Additional modifications to the trailer, including ducting and dust and noise seals, are discussed in Sections 8.4 and 8.7.

The single-wide trailer provides a low cost, mobile platform that provides adequate space for the HECS. In addition, it provides flexibility as there are several alternatives for potential expansion, if additional space is required.

8.1.3 Expansion Options

If additional space is needed, several options for expansion of a single-wide trailer were considered. First, a visitor walkway and viewing windows could be added outside. This would eliminate the need for a plexiglass wall and reduce the amount of area in the trailer dedicated to hallways. Secondly, an additional trailer could be added for conference room facilities, and the conference room area could be incorporated into the control area, or renovated to meet whatever future needs require. Lastly, a second trailer could be added and attached to the primary trailer with an air sealed walkway, virtually doubling the space available. These options provide increasingly more space, at an increasing cost, so the space and economic constraints should be considered when selecting an expansion option.

8.2 Racks

This section discusses the issues involved in selecting a type of rack, rack options, mounting of racks, and a recommended rack type for the HECS. Regardless of the type of racks chosen, guidelines for equipment placement include grouping similar equipment (similar processes) together, designing to eliminate potential electromagnetic interference, and putting the heaviest equipment at the bottom of the racks. In addition, equipment that may need tweaking or user interface should be placed at mid-height on the racks for easy access.

8.2.1 Options

There will be electronic equipment in the control room, equipment room, and geophysics room. The electronic equipment placed in the equipment room will be personal computer and workstation processors, data acquisition equipment, and sensing equipment. Not included are monitors, printers, and other equipment with output for the operators. The electronics in the equipment room will be contained in a rack system.

The racks serve several purposes. First, they house and protect the equipment. The degree to which the racks can protect the equipment in an application where mobility and modularity are requirements is an important factor. To narrow down the options that were available for racks, the following questions were asked:

- Will the equipment be protected by the racks if it remains in the trailer during transport?

- Can the equipment and/or the racks be taken out of the trailer and put back in quickly and easily without damaging the equipment?

- If the equipment requirements change, can the racks be modified?

- Can extra racks be removed, or additional racks added?

Flexibility and modularity are affected by the size of the racks. To be highly mobile, it is desirable to have small racks that can be stacked vertically and horizontally rather than big, bulky, cumbersome racks. Not only are they easier to move, but small racks also make the entire system more modular. This is because each rack can contain the equipment for one component of the control room. If that component goes away, then just that one small rack needs to be removed. Another rack containing the equipment for a new component could just as easily be moved in.

Because cool air must be routed both to them and through them, the racks form an integral part of the cooling system for the equipment. The layout of the rack (e.g., doors, vents, holes in the bottom or top) and how it can be mounted affect how easy it is to cool the equipment inside. As will be seen, this topic was a major contributor on the decision of which type of rack to recommend.

By looking at criteria such as modularity, mobility, protection of equipment, size, and ease of cooling, the type of racks to be used was narrowed down to two options.

- A small and rugged equipment case

- Modular racks that come in various heights.

The following two sections discuss these options, their advantages and disadvantages, and some possible vendors for either option. Based on the current requirements, the recommendation is to use the modular racks described in Section 8.2.3.

8.2.2 Equipment Cases

Equipment cases are polyethylene cases built around a standard 19-in. wide frame. The outside of the cases are ribbed so that they will "lock" together when stacked. Pictures of equipment cases are shown in Figure 4. Possible vendors for equipment cases are provided in Appendix H. Some other features that are typical of equipment cases are

- Standard 1.75-in. hole spacing in front and rear rails

- Water tight gasket and construction

- Inner frame depths up to 23 in.

- Removable casters

- Corrosion and fungus resistant

- Removable front and back

- Handles on sides

- Shock isolated inner frame.

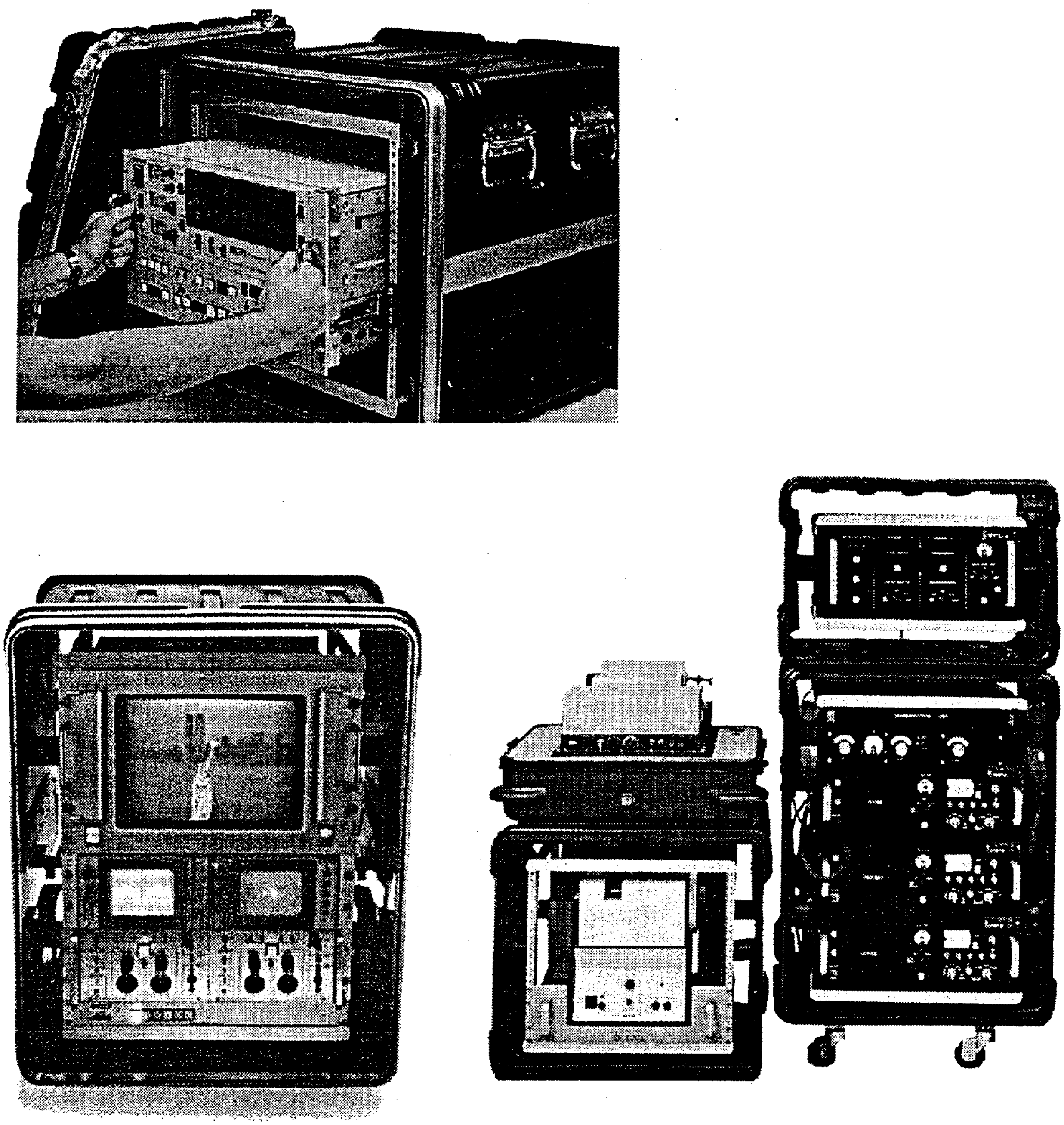

Figure 4. Equipment cases.

The major advantage of these cases is that they are rugged and mobile. The equipment would always be mounted in a way that it could easily be transported in its case by simply disconnecting the data and power cables. If the equipment is moved every couple of weeks, or even once a month, then these cases would be the best option.

There are some drawbacks to using these cases that are more important than their mobility if they are not going to be frequently moved. One such drawback is that because they are made to be moved around, they do not have an easy way to secure them to the floor. The easiest way would be to use straps to tie them down, but the effectiveness of this method is questionable. Another drawback is that the HVAC system would be more complicated. Because the only openings are in the front and back, these cases could not be mounted on top of a plenum. A fan or blower could be mounted on the standard 19-in. wide frame, but these do not provide as much cooling control and produce more noise than using a plenum. Finally, although the cases are mobile and modular, they are only as mobile and modular as the wiring needed to connect the equipment to the control room and integrate the system. Any new platform the equipment might be moved to, or any new piece of equipment added would still require all of the wiring that any other rack system might require. In addition, the placement of the equipment in these cases might require custom connector cables to reach the required distances.

8.2.3 Modular Racks

A modular rack system is recommended for the HECS. Pictures of this type of rack are shown in Figure 5. Only one company was found that sold these modular racks, however, a more extensive search would probably find others. The identified company, Optima, calls their modular racks the Modular Packaging System.

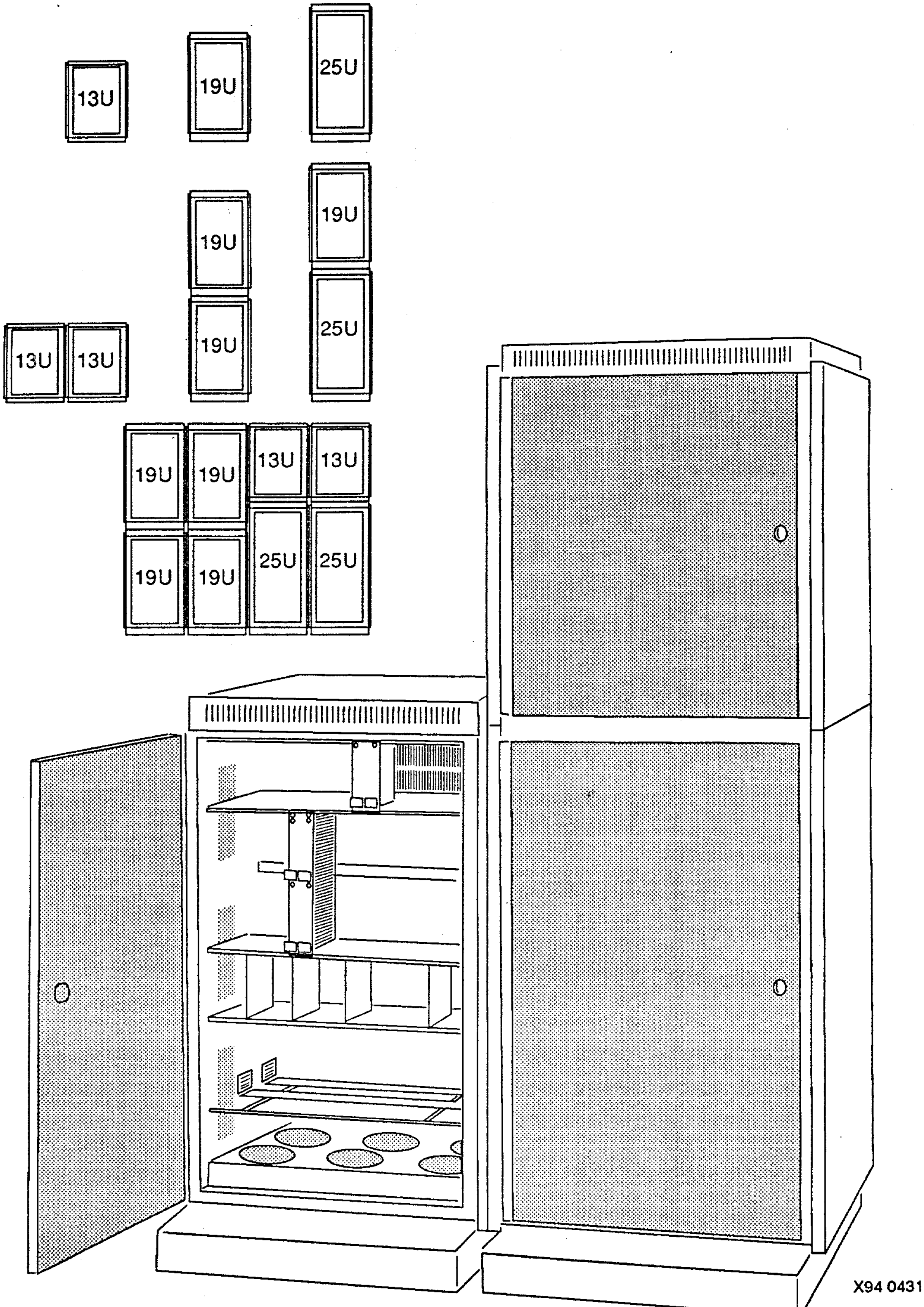

Figure 5. Modular rack system.

Optima Enclosures

- Gichner Systems Group, 2166 Mountain Industrial Blvd., Tucker, GA 30084-5088, 404-496-4000

- Optima Electronic Packaging Systems, Dept. B, 2166 Mountain Industrial Blvd., Tucker, GA 30084, 404-496-4041.

The modular racks are standard 19 in. wide × 24 in. deep. These racks come in three heights: 13U (23 in.), 19U (33 in.), and 25U (44 in.) and are designed so that they can be stacked on top of each other and attached on their sides. Different heights are available so each component's equipment (e.g., gantry crane, excavator, and conveyance,) can be housed in the same basic model even if the amount and type of equipment differs between systems. Separate housing for equipment makes the system modular because modules can be added or removed independently. For example, if one system requires additional equipment in the future, a taller rack can be purchased to house all equipment.

The HVAC design for these racks would be simpler than for equipment cases. These racks are a standard build and can be mounted over a plenum, as shown in Figures 6 and 7. As indicated in Section 8.4, this is a simple and flexible way to cool the equipment.

One drawback of these racks is that they are not as mobile as those in the previous section. Although more mobile than tall, "full-size" racks, these racks will need some extra stiffening to avoid damage during transport. Shock and vibration mounting is not as easy with these racks compared to the equipment cases. It may be necessary to remove the equipment and individually package them for transportation. This would not be inconvenient if moving occurs less than once a month, especially if the wiring system is designed to allow for easy connection and disconnection of the equipment.

8.2.4 Summary

Mobility, protection of the equipment, modularity, and HVAC design were used to determine which rack system would work the best. The modular racks, outlined in Section 8.2.3, are flexible and allow for changes in the future. They also support a simple HVAC system. These are the recommendation if equipment will be moved less than once a month. If more frequent moves will occur, it is recommended to use the equipment cases outlined in Section 8.2.2.

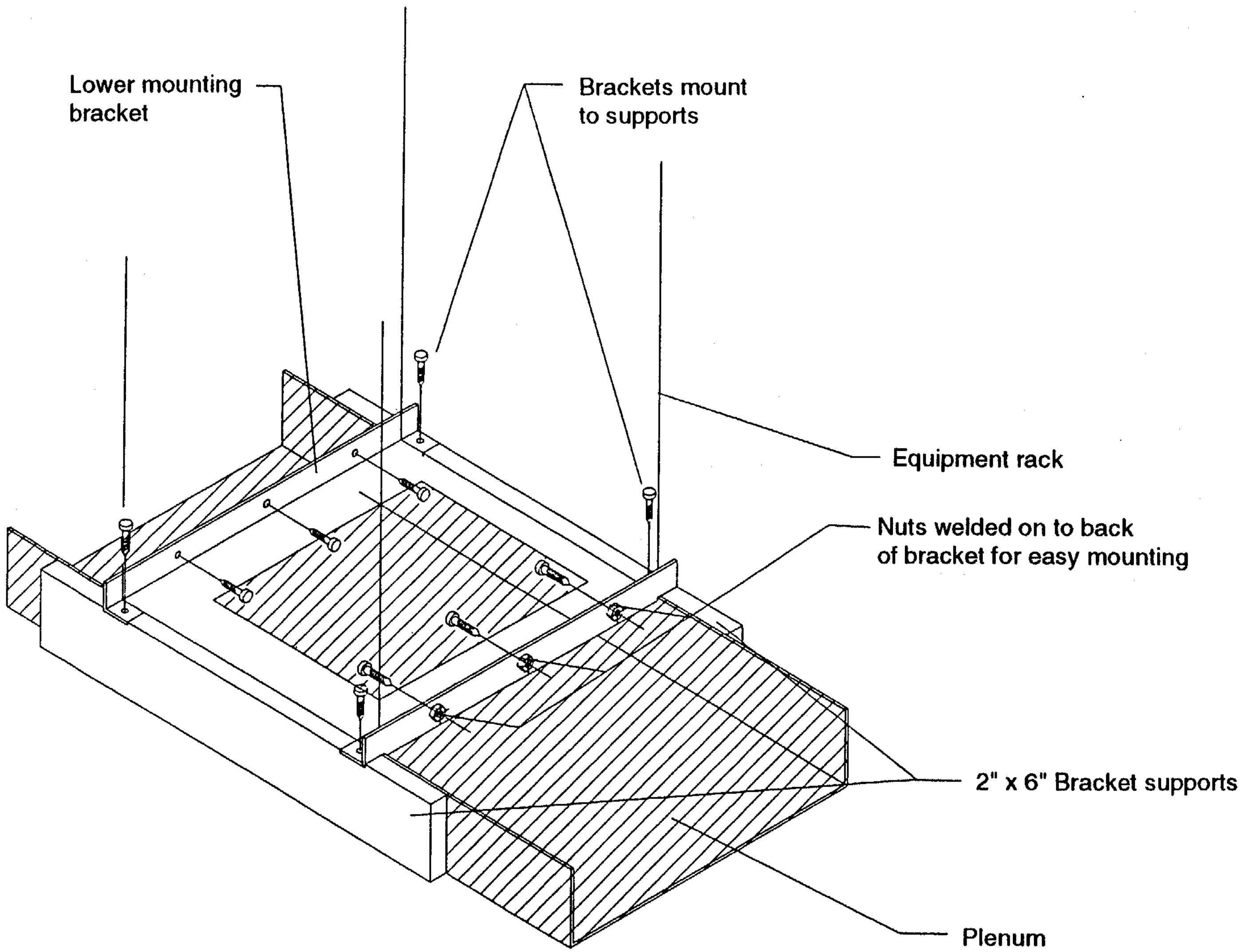

Figure 6. Equipment racks mount above plenum with angle iron brackets.

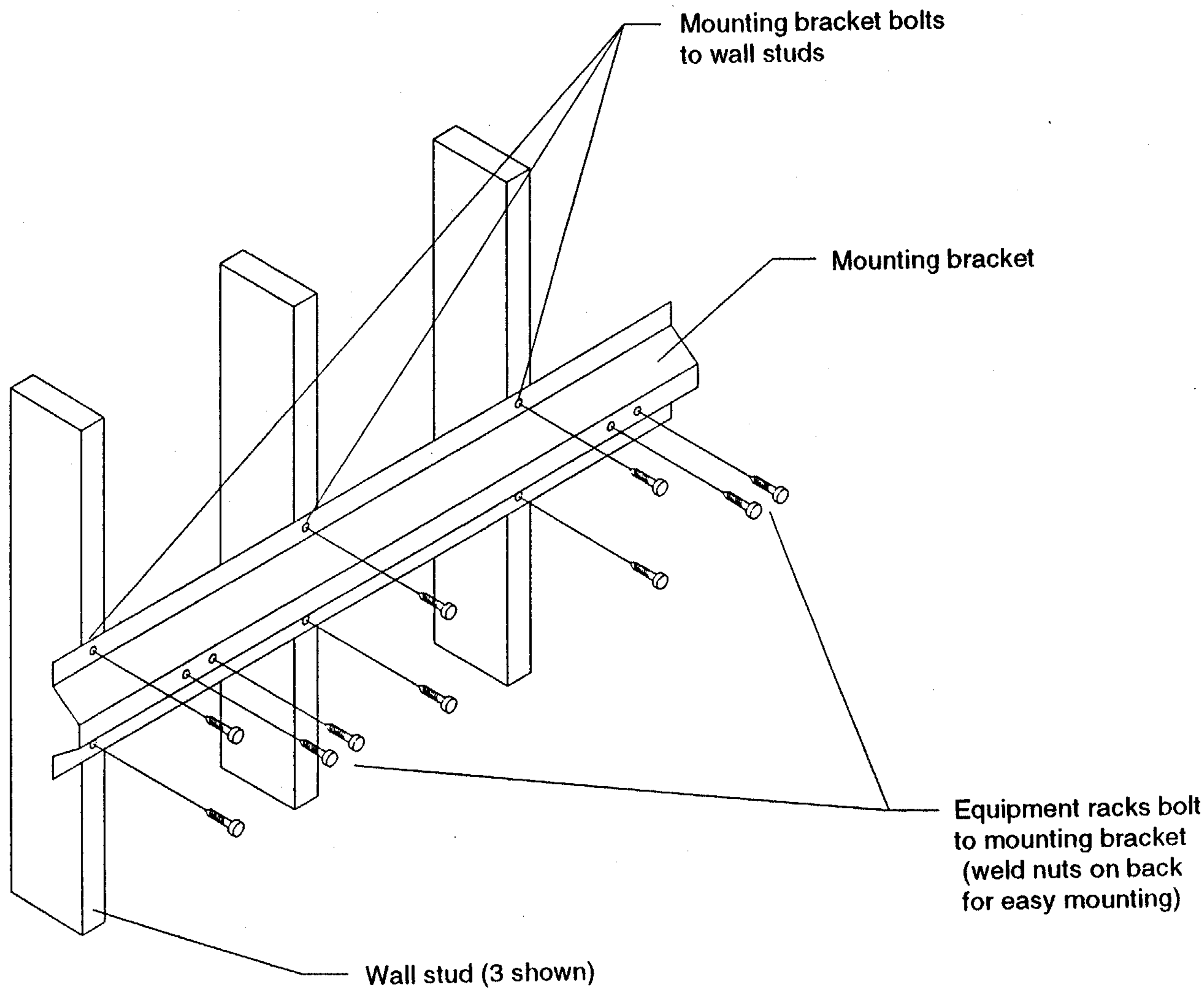

Figure 7. Back of equipment racks bolt to a mounting bracket.

8.3 Transport

8.3.1 Moving

The platform chosen is one with mobility, and the racks chosen do not include vibration/shock mounting. For these reasons, the issue of what to do with the equipment in the trailer when it is moved should be addressed. At this time the equipment has not been totally specified, so it is unknown whether it will sustain the shock and vibration of moving. For the same reason, it is not feasible to perform a detailed design including adding either shock mounting or rack reinforcement. The recommendation at this time is to remove the equipment from the racks and package it in padded containers for transport.

8.3.2 Shocks and/or Additional Axles

Since the equipment will be removed for transport, additional shocks will not need to be added to the trailer. However, if it becomes desirable to leave the equipment in the trailer during transport, additional shocks should be used and the equipment should be shock/vibration mounted.

As a manufacturing option, the trailer can be built with additional axles. This would be done if the equipment added to the trailer created too much weight on the standard axles and tires. This would also increase the amount of the trailer that is supported during travel and decrease the distance from support structure to heavy pieces of equipment. At this time, the weight of the equipment does not necessitate additional axles.

8.3.3 Stabilization (Jacks and Tie Downs)

Idaho regulations require one jack or support every 6 ft for single-wide trailers. Jacks will be used (rather than other types of supports) to increase mobility. Additional jacks may be needed under the UPS load, or if other heavy loads are installed in the trailer. The trailer will be leveled manually, rather than using hydraulic leveling jacks because moves are anticipated to be relatively rare. If more frequent moves are needed, hydraulic leveling jacks should be considered.

A single-wide trailer can withstand winds in excess of 50 mph without tie downs. Regardless of this fact, tie downs will still be used. Appendix B, Section 3.1 of *The DOE Architectural Engineering Standards* sheds some light on the issue of tie downs. It states that a unit must be able to withstand a horizontal wind load of 20 lb/ft^2 (9.8 g/cm^2) and a vertical uplift of 19 lb/ft^2 (9.3 g/cm^2). It also states that tie down protection shall be used.

8.4 Heating, Ventilating, and Air Conditioning

8.4.1 General Approach

To accommodate the different functional requirements (such as cooling), the HECS trailer will be divided into several different sections. The primary control area will include operators in the main control room and adjacent geophysics room. A majority of the electrical equipment will be located in a dust controlled equipment room. Lastly, a conference room will be available to accommodate guests and information meetings about the remediation or demonstration efforts.

Each of these areas is expected to have different heating and cooling loads, as well as different duty cycles. For example, the control room will normally have a stable number of occupants over an 8-hour period. However, the number of conference room occupants will vary significantly over this time period. In addition, it is desirable to ensure that the noise caused by cooling the conference room and equipment room does not affect the environment of the Control Room. Due to these factors, the HVAC design includes a separate HVAC system for each of these separate areas. In addition, a cooling system will be provided for the UPS, which will be located in a separate cabinet near the main entrance.

All of the HVAC systems use externally mounted HVAC units and insulated air ducts to supply the trailer. The HVAC units will be mounted on a separate trailer or pad and will not affect the height and length requirements for transport of the trailer. The HVAC units, generators, and other peripheral equipment can all be mounted on a common trailer separate from the HECS trailer. The trailer can be located so that it is central to the inlets and outlets for the HVAC loads. Externally mounting the HVAC units will provide a quieter environment, will reduce the Electromagnetic Interference (EMI) and vibration affects on other equipment, and will allow for easy access for maintenance as well as easy transport. A separate power system (generator) can be used for the HVAC systems so that the workstations are protected from power losses and power surges during start-up.

It is expected that the HVAC systems will keep the humidity in the range between 30 to 70%, which will provide a comfortable environment while controlling static electricity for the users. Dust and static electricity will be controlled by the use of electrostatic filters. These filters should be a style that is easily removed and cleaned.

The majority of this section deals with cooling the HECS trailer. The equipment room and control room may generate enough heat while the equipment is on so that no additional heating would be required. However, supplemental heat units should be added to these AC units for times when the equipment is off. The conference room will also require a supplementary heater for the cooler months of the year.

If the HECS will be unoccupied for extended periods of time, it may still need to be kept at reasonable temperatures (either by heating or cooling) to protect temperature sensitive equipment. Another option is to remove all of the temperature sensitive equipment from the trailer during periods when it is not being used.

The final HVAC system design should include an analysis of the recommended startup and shutdown sequences for the HECS trailer. For instance, on a cold day, the equipment room and work areas should be allowed to warm up before turning on the equipment. Likewise, on a hot day, the air conditioning system should be run until the trailer is within the recommended operating temperature before turning on the equipment. This recommended procedure should be included in the HECS system operating procedures.

8.4.2 Conference Room

Blower systems were selected for the control room and conference room. These systems will provide the ventilation needed and will allow the occupants to direct airflow to specific areas that require more cooling. The blower systems for the control room and conference room are independent systems. A stand-alone external HVAC unit will produce the cool air carried to the trailer through insulated ducts. These ducts will connect to the existing ductwork in the trailer for distribution (see Figure 8). The ductwork will have to be modified to separate the conference room and control room. Because there is only one existing vent in the conference room, the ductwork will have to be modified further to include additional vents. It is expected that adding vents will not significantly affect the noise level of the HVAC system. Although a detailed analysis and design is not possible at this time, it is expected that for the unmodified duct system parts of the ductwork would have airflow to serve five vents. If redesigned correctly, the existing ductwork would probably still not serve more than five vents. In the final design, it is recommended that an analysis of the airflow and noise levels be done to verify that the existing ductwork is adequate. If the airflow causes excessive noise levels, replacing the existing ductwork may be necessary.

The cooling requirements for the conference room will be strongly dependent on the number of occupants. The HVAC unit for this room will not likely be on full power all the time, but only when the room is full. For the purpose of sizing the air conditioning unit, calculations where made on the basis of a full room. Using the *Uniform Building Code*[6] it was determined that the conference room could hold 12 people. This was adjusted to 15 people for a worst case scenario of the cooling load. The calculations for the cooling load in the conference room can be found in Appendix I. The assumptions that were made for these calculations are

- Temperature differences across interior walls are small, so heat transfer is negligible.
- All other assumptions are listed in their appropriate places in Appendix I.

The method of predicting the cooling load is a Cooling Load Temperature Difference (CLTD) method presented in the *1981 ASHRAE Fundamentals Handbook* (Chapter 26).[7]

The results from the calculations in Appendix I are that, with a Safety Factor of 1.5, the total cooling load in the conference room is 9.62 kW (almost a 3 ton unit).

8.4.3 Control Room

As stated above, blower systems were selected for the control room and conference room. These systems will provide the ventilation needed and will allow the occupants to direct airflow to specific areas that require more cooling or heating. The blower systems for the control room and conference room are independent systems. A stand-alone external HVAC unit will produce the cool air carried to the trailer through insulated ducts. These ducts will connect to the existing ductwork in the trailer for distribution (see Figure 8). The ductwork will have to be modified to separate the conference room and control room. Because there are only two existing vents in the control room, the ductwork will have to be modified to include additional ducts. Also, the workstations in the control room will include individual airflow outlets for each user to control the air directed toward them. The outlets will be much like the ones found overhead in airplanes, and cool air can be supplied from the same source as the rest of the room.

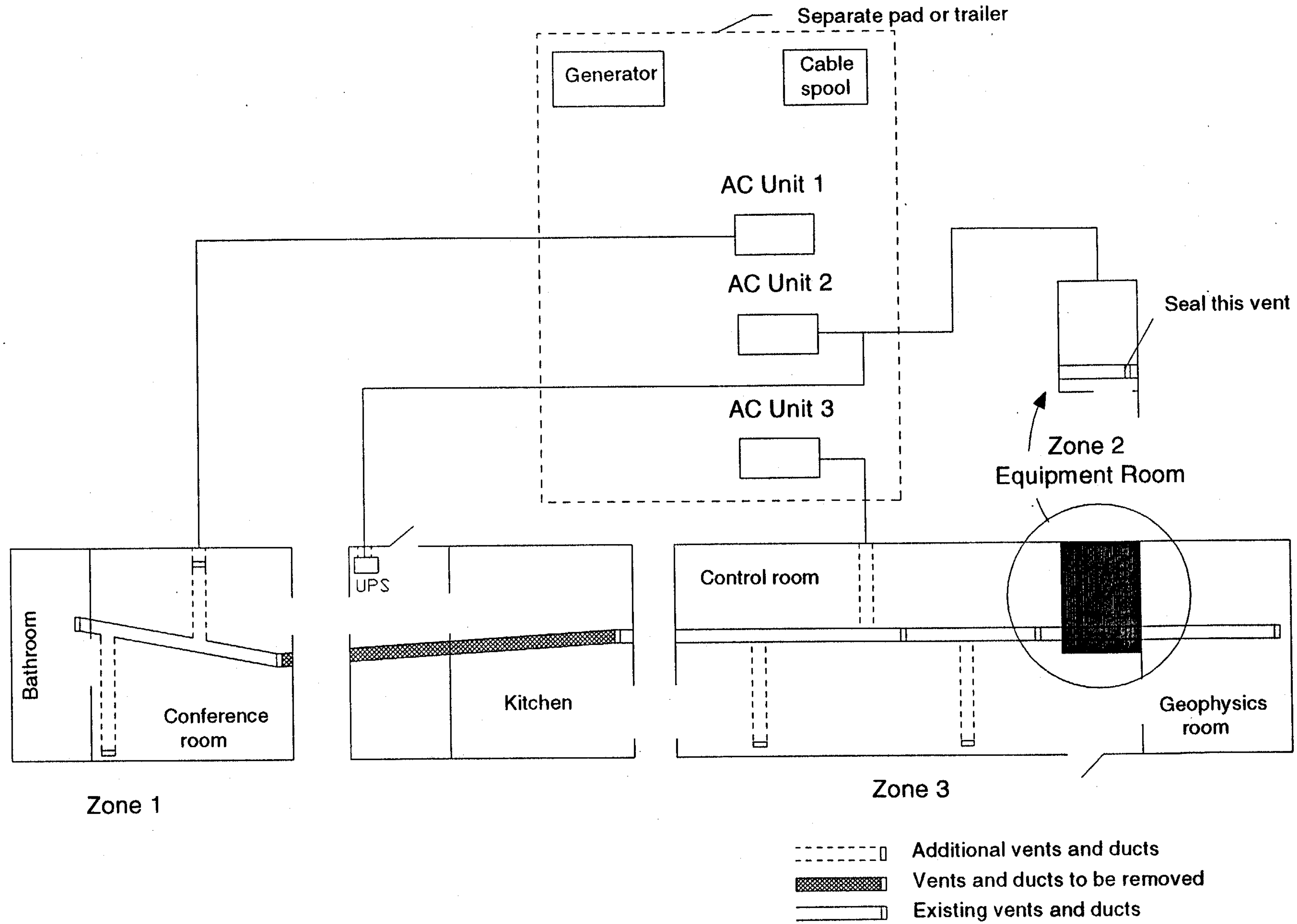

Figure 8. Ductwork in trailer.

The cooling requirements for the control room will be strongly dependent on the number and types of equipment in it. For the purposes of this conceptual design, a typical system is presented. The calculations for the cooling load in the control room can be found in Appendix I. The assumptions that were made for these calculations are

- Temperature differences across interior walls are small, so heat transfer is negligible.

- The equipment numbers are based on the knowledge of what the gantry crane will require and the assumption that conveyance, excavator, and the supervisor workstation will each require the same.

- All other assumptions are listed in their appropriate places in Appendix I.

The method of predicting the cooling load is a CLTD method presented in the 1981 ASHRAE Fundamentals Handbook (Chapter 26).[7]

The results from the calculations in Appendix I are that, with a Safety Factor of 1.5, the total cooling load in the control room is 15.7 kW (about a 4.5 ton unit).

8.4.4 Equipment Room and Uninterrupted Power Supply

A plenum system was selected to cool the Equipment Room. A plenum system uses a high pressure supply, rather than a high airflow rate, to provide cooling. This system produces less noise than a blower system and provides cool air directly to the racks. The amount of cooling for specific areas can be controlled with the duct sizing. The system includes natural convection because the cool air supply is located near floor level, while the warm air returns are located near ceiling level. Figure 9 shows a typical plenum system.

One option considered to supply cool air to the plenum was to mount the HVAC unit in the equipment room, with the condenser side of the unit located outside the trailer. The primary drawback of mounting the unit in the equipment room is the added height to the roof by mounting the condenser externally and the added risk of coolant leaks during disconnection if the condenser were mounted elsewhere. If a system such as this were used, quick disconnects should be used on the freon lines to prevent losses.

The option selected was to mount the unit entirely external and locate it on a separate platform or trailer. This provides the following advantages: easy replacement and/or maintenance, no changes to the trailer dimensions, no modifications to the trailer for mounting, and reduced noise, EMI, and vibration affects.

With a stand-alone external HVAC unit, insulated ducts will carry the air from the HVAC unit to the trailer. The round inlet hose will be transitioned to a rectangular "U" shape at the floor level so that the noise and cooling loss are minimized. The "U" shape (plenum) will run under the racks, and plates will be used to cover areas where future racks may go. The floor under the equipment racks will be raised to accommodate the plenum (see Figure 10). In addition, the remainder of the

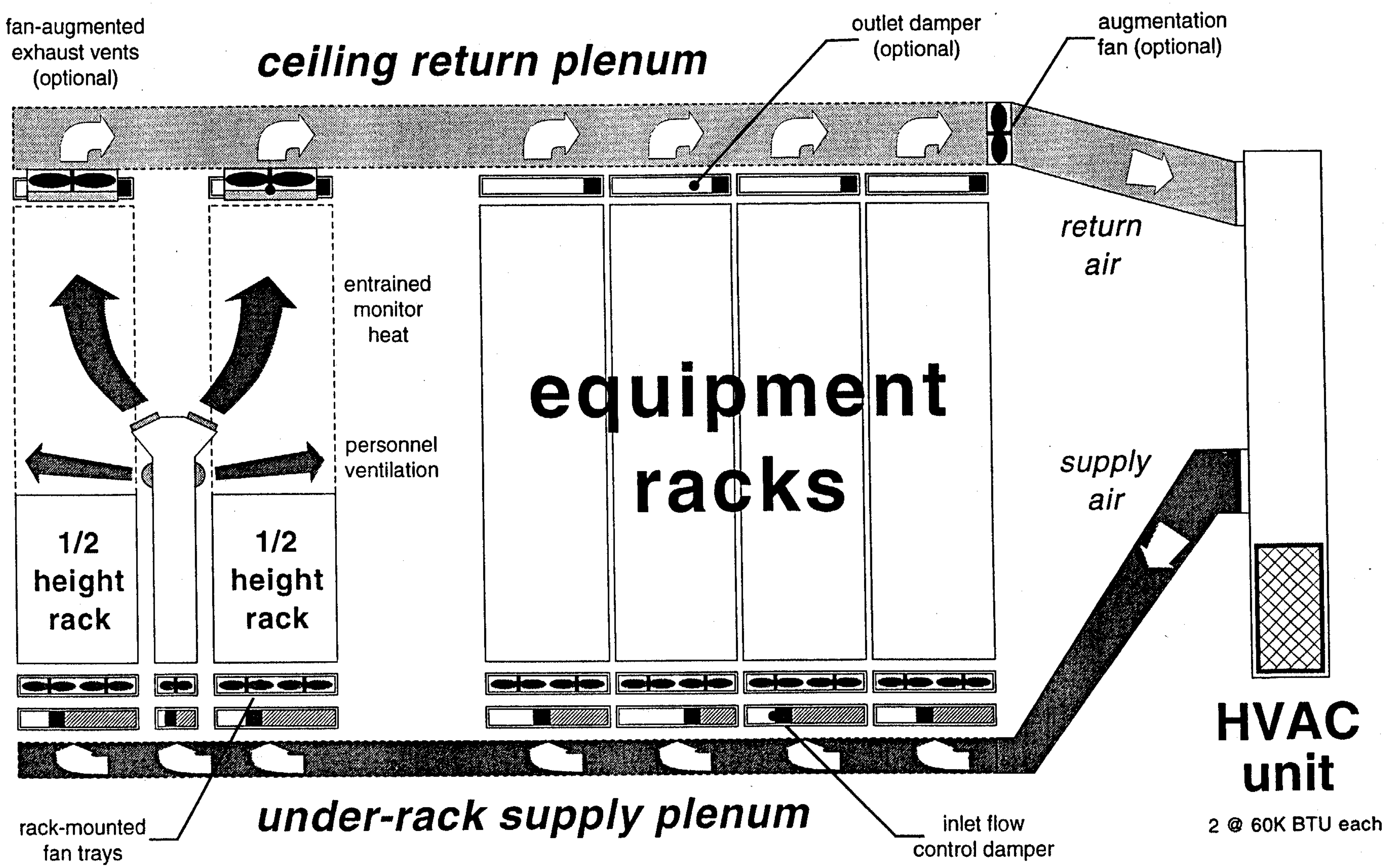

Figure 9. Typical plenum system.

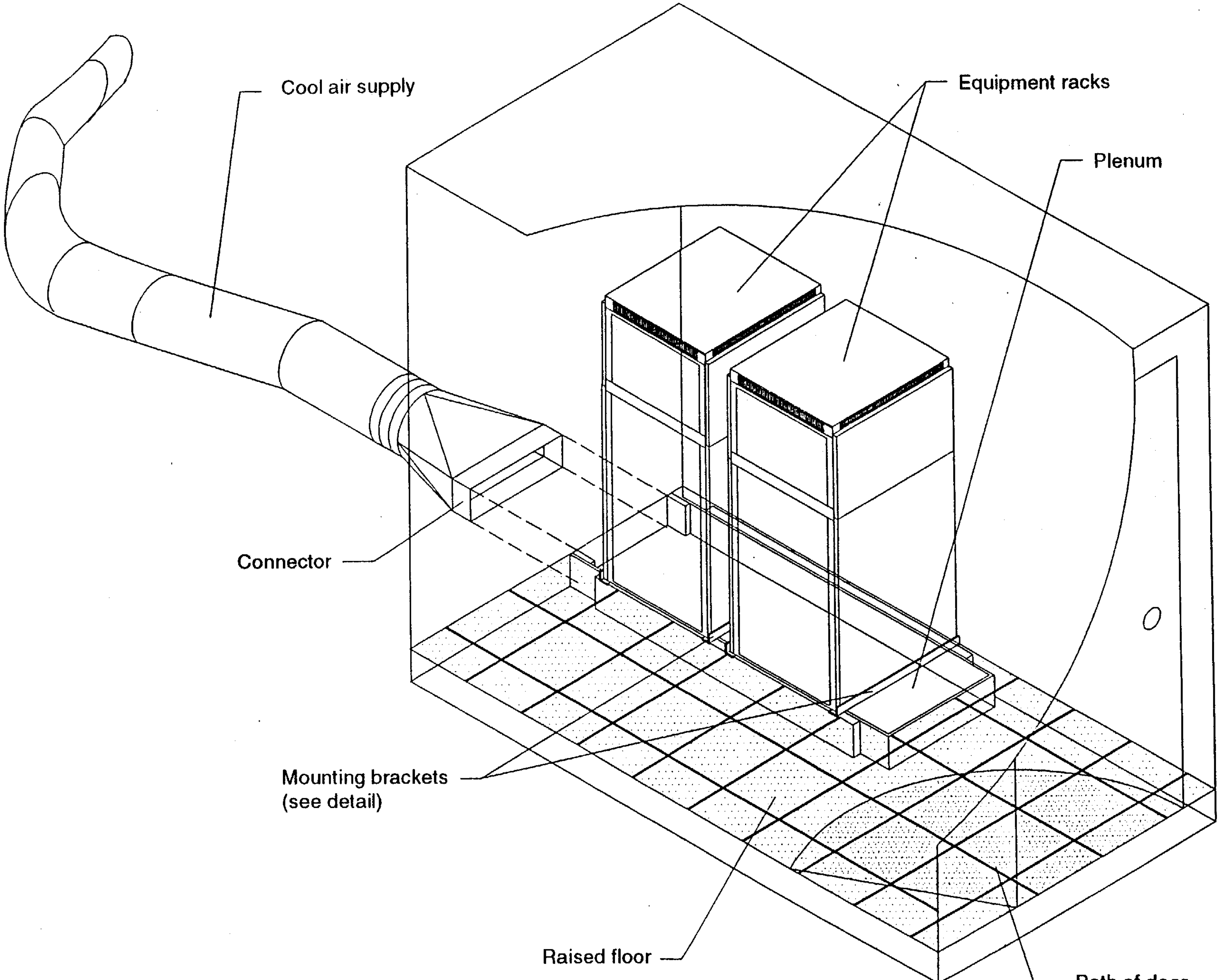

Figure 10. HECS equipment room.

floor in the equipment room will be raised to allow flexibility for future additions or changes (floor loadings are discussed in Section 8.5).

A constant compressor with a hot gas bypass will control the HVAC unit so it provides cooling only when needed while avoiding repeated startup and shutdown cycles. A constant running compressor will provide a constant noise, avoiding distracting startup noises.

The UPS will be cooled by the same system as the equipment room, with the ducting split outside the trailer to the equipment room and the UPS. Because the cabinet that the UPS will sit in is located by the door, it may see large temperature fluctuations in the air around it. For this reason the temperature of the UPS and the cabinet air will need to be controlled by a thermostat.

The cooling requirements for the Equipment Room will be strongly dependent on the specific equipment selected. For the purposes of this conceptual design, a typical system is presented. The calculations for the cooling load in the equipment room can be found in Appendix I. The assumptions that were made for these calculations are

- There are no windows in the equipment room (this would be the best design and should be done).
- Temperature differences across interior walls are small, so heat transfer is negligible.
- The entire control station will require six workstations and two personal computers. This is based on the fact that the gantry crane will require one work station and one PC.
- All other assumptions are listed in their appropriate places in Appendix I.

The method of predicting the cooling load is a CLTD method presented in the 1981 ASHRAE Fundamentals Handbook (Chapter 26).[7]

The results from the calculations in Appendix I are that, with a Safety Factor of 1.5, the total cooling load in the equipment room is 11.1 kW (a little over a 3 ton unit), and the cooling load from the UPS is 2.1 kW. For the UPS and the equipment room combined, a unit capable of 13.2 kW (approximately 3.5 tons) will be required.

8.4.5 Summary

The HECS trailer will accommodate different functional requirements, and each of these will have different cooling and heating loads. Because of this, the trailer has been divided up into three sections or zones: conference room, control room, and equipment room. The UPS will be cooled by the same unit as the equipment room; however, it will not be located in the equipment room. The conference room and the control room will be cooled with blowers, and modifications will need to be made to the existing ductwork. The equipment room will be cooled by a plenum. Each section will have a separate air conditioning unit, all of which will be mounted entirely external from the trailer. This system provides the advantages of reduced noise, EMI, and vibration affects, low cost installation, and heating and cooling designed to meet the specific needs of each area.

8.5 Floor Loading

8.5.1 Assumptions

A sample analysis of the floor loading is presented in this section. This analysis is presented in outline form, and it is expected that modifications and a complete analysis will be performed for the final HECS configuration. For the analysis provided here, it is assumed that a single-wide trailer (Guerdon Model 47611)[5] is used as the HECS platform. In the final analysis, a factor of safety should be used. It is assumed that the UPS is the heaviest load to be added to the trailer. A particular UPS (see Section 8.6) was selected for this analysis. A raised floor for the selected platform should be used to accommodate cooling in the equipment room. The floor loading should be analyzed for the specific equipment selected. Although no calculations or approach for the floor loading in the equipment room is presented, it is assumed that this analysis would be of the same form as that presented, and that once the final equipment is selected and the configuration is known, this analysis would be performed. Appendix J shows the calculations that will need to be performed.

8.5.2 Results

The results of this preliminary analysis show that the location selected for the UPS is directly on top of one of the trailer's main supporting I-beams. For this configuration and the UPS selected, it is inherently obvious that the I-beam will easily support the load, and no further analysis is required. For future reference, a typical approach to a floor loading analysis will be presented here. If the UPS model changes, or its location moves, or a different HECS platform (building) is used, a detailed floor loading analysis should be performed.

8.6 Electrical Considerations

8.6.1 Uninterruptible Power Supply

The UPS system is an important part of the HECS. It provides reserve battery power and line conditioning to produce a constant output waveform. Ideally, this waveform should be 120 V/60 Hz and sinusoidal, regardless of the input. In a normal situation, any UPS of sufficient size would be satisfactory. BWID, however, is generating power from an AC generator as opposed to obtaining it from a utility line. Obviously, a generator will be more susceptible to large loads and feedback produced by the loads. Most UPSs, unfortunately, produce feedback harmonics when connected with loads. The undesirable effect of feedback, when large enough, causes a generator to produce frequency fluctuations. The fluctuations will, in turn, cause the UPS to continually switch from line to battery voltage. The perpetual switching severely shortens the life of the batteries and may cause a system shutdown.

One method for overcoming the limitations of a generator is to provide a separate power source, at least 30 kW, for the UPS. A 30 kW devoted generator will not be as susceptible to feedback because it can overpower any harmonics. If the generator is loaded, it would reduce its ability to combat feedback. This solution is simple but may not always be viable. A better solution would be to use a system that is designed to induce minimal feedback when connected to a generator.

Based on a review of various UPS systems, the following requirements were set:

1. 10 kVA or 8 kW

2. Less than 5% total harmonic distortion

3. An adjustable input frequency of at least +/- 5 Hz

4. Efficiency rating greater than 87%

5. An output frequency of 60 Hz +/- 0.5 Hz

6. Remote monitoring capabilities

7. Quick service (preferable within 24 hours).

Additional factors that should be considered are cost, pretesting ability, documentation, experience of vendor, and ease of installation. Assumptions in determining the type of UPS included

1. The UPS should be at least 10 kVA or 8 kW

    a. 6 SUN workstations at 1,000 VA each

    b. 15 monitors at 100 VA each

    c. Safety margin of 2.5 kVA

2. Single-phase generator and UPS

3. Minimum of 30 minutes battery power

4. HVAC will not be powered by the UPS.

To connect the equipment to the UPS, a distribution box and receptacles will be required. The conditioned power from the UPS will enter the box and will be routed to breakers that are connected to the receptacles. The user's guide to the UPS will give a detailed wiring outline. Also, as a good rule, the receptacles connected to the UPS should be a different color, such as orange. This will eliminate the possibility of confusing a receptacle providing conditioned power with a receptacle connected to the raw power of the generator.

8.6.2 Generators

To accommodate the power needs for the HECS, it is important to follow a few guidelines. First, a good rule to use when dealing with generators and computer equipment is to oversize the generator by a factor of three. By increasing the size of the generator, a large power draw will be less likely to produce feedback on the output of the generator. Also when using sensitive computer equipment, a separate generator may be desired.

For the HECS, the greatest consumers of power will be the HVAC systems and equipment. Based on the assumptions for the HVAC and UPS, the requirements are

1. 3 HVAC systems:

   a. 9.6 kW cooling load/4.2 kW power required
   b. 15.7 kW cooling load/6.8 kW power required
   c. 13.2 kW cooling load/5.7 kW power required

2. UPS that controls the equipment at 10 kW.

Using these rules, the HECS will require a generator capable of handling approximately 90 kW (with a safety factor of three for computer equipment). If two generators are used, the HVAC generator should be 20 to 25 kW (with no safety factor since no computer equipment is involved), and the generator for the UPS and trailer should be 28 to 32 kW. Generators meeting these requirements can be rented at the site.

8.6.3 Power Distribution

For the single-wide trailer, the best option for distributing the power would be to use the present system in the trailer. The trailer is wired to handle a 200 amp electrical service. This is sufficient to handle the lights, refrigerator, UPS, and computer equipment. To make it even easier, the UPS has been situated so that it can be adapted to use the receptacle presently reserved for the dryer. The only drawback to using the trailers present system is that the HVAC will need to be wired to a separate distribution box.

8.7 Overall Trailer Considerations

8.7.1 Noise and Dust Seals

The plexiglass wall between the control and conference areas will provide a significant amount of dust sealing. In addition, the access door in the plexiglass wall should have weather stripping or dust seals to further increase dust protection. The equipment room door should also include dust seals. All of the ports (e.g., electrical, air) into the trailer should include the capability of being sealed for dust protection during transport.

The plexiglass wall between the control and conference room areas also provides noise protection. In addition, noise damping may be required between the equipment room and control area, primarily on the door. The UPS is expected to generate a 52 dB noise (about the same as a comfortable passenger car travelling on a freeway) at 60 Hz. Because of the low frequency, noise damping on the UPS cabinet may not be necessary. To further reduce noise, the generators can be located remotely from the trailer.

8.7.2 Cable Spool

A cable spool will be required to hold 500 ft of cable that transmits signals from the remote building to the HECS control station. The cable should be designed for outdoor use (i.e., water proof and UV protected) and may need to be buried to prevent damage. Also, it is important to consider the torque threshold of the cable. The cable needs to withstand the tensile force when wound for transport. The cable spooler should be driven by a slow, low torque electric motor. The use of a low torque motor is to prevent stretching the cable if it gets caught during winding. If it needs to be wound up manually, the device should be designed with a crank so that it can be wound by one person. In addition, it is recommended that a backup winding mechanism, such as a drill with the appropriate chuck, be included. The cable spooler will be mounted on the trailer or platform with HVAC units and a generator.

9. HECS COMMUNICATIONS

This section discusses the preferred communications system for the HECS. Appendix K provides information on all of the communications systems that were reviewed.

A single coaxial cable, broadband communication system is recommended for the HECS. The reason for proposing this broadband communication system is that up to 50 NTSC, one way, broadcast video channels may be needed between the excavation building and control station. All systems will utilize video as a major portion of their operation and control scenario. Some HECS systems anticipate 10 or more cameras. To support these numbers, the initial configuration of the communications system will provide video channels for approximately 50 cameras. All 50 camera input shall be capable of being accessed by authorized operators of any HECS system. A single coaxial cable with distributed taps (each receiving a video camera/video modulator input in the excavation building, and transmitting, via the coaxial cable, to a number of channel selectors feeding video monitors in the control building) is the cheapest, simplest, and most reliable method for all participants to unobtrusively share all available video information. This method allows any user to access any video signal at any time, irrespective of the source. Video routers or switchers, beyond the simple and inexpensive channel selectors and monitors, are not needed. The selection of the video to be viewed can be either manual or programmable.

To support both the video and data needs, a closed circuit television (CCTV) type broadband communication system is proposed. There are several reasons for this proposal. Simplicity and portability are requirements that could be fulfilled by the CCTV broadband system. Finally, the cable has spare available bandwidth that allowed for future expansion and flexibility.

The proposed common communications network for the HECS is a Mid-split, 5 MHz to 550 MHz broadband, coaxial cable or fiber optic cable, CCTV type communications system. This network has the capability to carry all the HECS data between the two shelters. The broadband data highway has channel limitations and so resources will need to be managed. The broadband network also has the unique capacity to support the controlled sharing of data between systems by placing all data on the broadband network in frequency divided slots or bands. With the proper equipment and proper authorization, these data can be accessed by others. It should be noted that without the proper equipment and the proper authorization the data cannot be accessed, and each system's data are secure to the system. Each frequency band is like a separate wire running within the broadband cable between each system's dedicated subassemblies or components. The broadband cable will run from the excavation shelter, where a break-out cabinet will be provided to interface with all users' data input/output (I/O) to another break-out cabinet in the control building, to offer data I/O for all the users' control stations and systems within the control building.

Typically, all externally directed computer data traffic between systems will run on a common TCP/IP Ethernet link carried on the broadband network. Normal data exchange between all existing processor systems can be supported by one Ethernet network, with the possible exception of passing and supporting real-time imaging and modeling data between systems. The broadband has the capacity of carrying more than one independent Ethernet, as well as other direct data links capable of transferring higher speed data, that could support the direct exchange of imaging and modeling data. The nature of what will be processed, and how, has yet to be determined.

In the event that video needs are greatly reduced, the broadband technology may not be the best or the cheapest way to handle the resultant data. For the limited amount of computer and control traffic needed, intelligent routers are readily available. These are typically fiber optic linked bridges, switchers or multiplexers capable of handling Ethernet, limited video, RS-232 or RS-422 data traffic. The gantry crane team is currently in the process of independently acquiring intelligent routing equipment to satisfy their immediate data needs. Such systems are adequate for independent projects, but a broadband system would be cheaper and provide more flexibility (including data sharing) if the systems are integrated into one common system.

To provide an interconnection between the computer systems in the HECS, an Ethernet is recommended. As of yet, the network does not have a specific purpose, but it is inexpensive and could be invaluable at a later date.

10. COLLISION AVOIDANCE

One important feature that should be implemented into an integrated remote characterization and retrieval strategy is collision avoidance. Collision avoidance refers to a system that would prevent equipment from colliding during operations, despite the human's control inputs. In other words, it is an equipment protection system.

Collision avoidance systems can also be too restrictive in that sometimes the robots need to directly touch each other or the ground. Some examples include the excavator bucket digging into the ground and the transfer of the waste from the excavator or gantry crane to the conveyance system. Therefore, some type of override is required to allow equipment to touch when desired. For normal operations such as the examples just given, an automatic override should be available so that the operators do not constantly hold down (or eventually tape) the override button/switch.

This section describes the HECS collision avoidance system. Section 10.1 gives the proposed concept. Section 10.2 presents four conceptual collision avoidance system options. Appendix L describes the collision avoidance systems that are available off-the-shelf. Appendix M is a Functional and Operational Requirements Document that could be used to develop specifications to procure a positioning system to aid in collision avoidance.

10.1 Collision Avoidance System Concept

The HECS collision avoidance system would provide protection from collisions between any of the remote operated systems (gantry crane and its subsystems, excavator, and conveyance system) and between each of these remote systems and immobilized obstacles (such as air monitors and large objects). The HECS would receive position data from each of the remote operated systems and stationary obstacles. Position of stationary obstacles could be accomplished manually, using the gantry crane (as a touch system to get position data), with sensors on each piece of stationary equipment or through a visual scanning system. The gantry crane and excavator end effector positions are known and could be used to touch obstacles to provide obstacle position data. The gantry crane or excavator would need to be used for large obstacle positioning since large obstacles would be placed during operations. Position data would be input to the Central Processor (CP). The CP would use position data to compute the 3D relationship of each of the remote operated system to each other and the operating environment. The output data from the CP is passed to the operations through a display or alarm. If a collision was impending, then an automatic protective function would be initiated. The operator's display would generate and display various 3D images that allow a visualization of the entire retrieval environment. The positioning system would only be to provide collision avoidance features. Other systems would need positioning data to supply other types of information. For example, the digface characterization would require position data from the gantry crane for the characterization information. Based on this concept, the following features for the collision avoidance system will be required.

- The 3D location of each of the remote systems, including mobilized appendages, shall be continuously monitored by the collision avoidance system, through a combination of a tracking system (for position and orientation) and acquiring data from each of the remote systems (for configuration).

- The 3D location of immobilized obstacles, that could be a concern for collisions, shall be determined by the collision avoidance system.

- The collision avoidance system shall, in real time, predict collisions and alert the operators with a warning alarm. If the operators fail to take action needed to mitigate the predicted collision, the collision avoidance system shall initiate an automatic shutdown signal to the appropriate remote equipment to prevent collision. The collision avoidance system shall, in real time, compute two overlapping volumes for each mobilized system and obstacle. The inner overlap would be red and the outer overlap would be yellow (to signal a warning of impending collision). The HECS shall initiate an alarm condition to the operators when yellow volumes contact and initiate automatic action to stop equipment when red volumes contact.

- The HECS shall, in real time, display an image of the retrieval environment showing the location of all the mobilized systems and fixed obstacles to the operators (with overlapping yellow and red volumes as equipment nears other equipment).

- The collision avoidance system shall have special override features to accommodate the case where mobilized systems or obstacles must contact each other. The override will be automatic for routine functions, such as the excavator placing waste in the conveyance system, but will require manual override for nonroutine functions, such as using a crane arm for maintenance on the excavator.

- The collision avoidance system should be designed (both hardware and software) to be distributed, flexible, and expandable. Not only should it be able to accommodate additional remotely operated systems for collision avoidance, but the computer power should be expandable to accommodate additional data acquisition and processing functions.

10.2 Conceptual Collision Avoidance System Options

Four different conceptual options were developed to support collision avoidance. These options include (1) full solids models on all remote systems, (2) limited solid models of remote systems, (3) a video intensive system, and (4) a video intensive system with on-board sensors. Each of these options is discussed below. Section 10.2.5 gives a summary of these options and provides discussion for application to the HECS.

10.2.1 Full Solids Models

A concept for a full solids model for the remote retrieval environment, including both mobilized system and static obstacles includes the following:

- Each remotely operated system would have location sensors and all appendages would have resolvers so that adequate data could be obtained to locate all aspects of the remote system in 3D space.

- The position data from each position sensor and resolver would be put into a high end workstation central processor that would compute (in real time and in 3D space) a high resolution solid model for each of the remote systems.

- Features on some of the remote systems and the central processor software would allow for position data of obstacles to be generated and built into the 3D model of the retrieval environment.

- The central processor would use the real-time 3D model of the retrieval environment to generate a high resolution graphics display, predict collisions, initiate alarms, and command the generation of shutdown anticollision signals to affected remote operated systems.

- The HECS would have a computer generated, limited solid model display of the retrieval environment. The HECS would also provide multiple video monitors with a video switch to access all video data. In addition, the HECS would have an alarm panel that would warn operators of impending collisions.

- A video system would obtain video images of all aspects of the retrieval environment. The system would have an array of video cameras and would provide access to all video data from each of the remote operated systems.

- Collision override features would be provided to allow the remote systems to perform tasks where equipment must contact. Automatic override features would be required for routine operations.

10.2.2 Limited Solid Models

Another option is to utilize limited solid models to aid operators to avoid collisions. The limited solid model concept is summarized below.

- Each remote operated system would have a position sensor that locates the system in the retrieval environment.

- A central processor would use position data to locate a worse case solid model of each remote system in 3D space that could be used to predict collisions. The central processor would issue alarms of potential collisions.

- Sensors and a processor on/off board that is part of each remote system would detect potential collisions and issue shutdown commands to the system to prevent the collision. The appropriate data from the system would be passed to the HECS to be displayed to operators.

- The HECS would have a computer generated, limited solid model display of the retrieval environment, multiple video monitors with a video switch to access all video data, and an alarm panel that would warn operators of impending collisions.

- A video system would obtain video images of all aspects of the retrieval environment. The system would have an array of video cameras and would provide access to all video data from each of the remote operated systems.

- Collision override features would be provided to allow the remote systems to perform tasks where the systems must contact. Automatic override features would be required for routine operations.

10.2.3 Video Intensive System

Another concept for collision avoidance is a video intensive system. Following is a summary of the video intensive system concept.

- The HECS would have multiple video monitors with a video switch to access all video data and an alarm panel that warns operators of impending collisions.

- A separate operator would monitor the remote systems via the video data and issue anticollision alarms to the appropriate remote system operators. Any of the operators would be able to initiate emergency shutdown commands to any of the systems.

- This HECS would not have a central processor. Operators would follow procedures to perform the function of the central processor by identifying potential collisions and preventing such collisions.

- A video system would obtain video images of all aspects of the retrieval environment. The system would have an array of video cameras and would provide access to all video data from each of the remote operated systems.

10.2.4 Video Intensive System With On-board Sensors

The final option is to utilize a video intensive system with on-board sensors to aid operators to avoid collisions. The concept is summarized below.

- The HECS would have multiple video monitors and a video switch to access all video data and an alarm panel (manually excited) that warns of operators of impending collisions.

- A separate operator would monitor the remote systems via the video data and issue anticollision alarms to the appropriate remote system operators. Any of the operators could initiate emergency shutdown commands to any of the systems.

- The HECS would not have a central processor. Operators would follow procedures to perform the function of the central processor by identifying potential collisions and preventing such collisions.

- Sensors and a processor on/off board for each remote system would detect potential collisions and issue shutdown commands to the system to prevent the collision. The appropriate data from the system would be passed to the HECS to be display to operators.

- A video system would obtain video images of all aspects of the retrieval environment. The system would have an array of video cameras and would provide access to all video data from each of the remote operated systems.

- Collision override features would be provided to allow the remote systems to perform tasks where they must contact each other. Automatic override features would be required for routine operations.

10.2.5 Summary and Discussion of Collision Avoidance Systems

Collision avoidance systems can aid operators by avoiding collisions through alarms and automatic shutdown features. The collision avoidance system would thereby reduce operator workload and possibly increase productivity because the operators would not be worried about a collision and could move equipment in a different manner.

Four options for collision avoidance were presented: (1) full solids models on all remote systems, (2) limited solid models of remote systems, (3) a video intensive system, and (4) a video intensive system with on-board sensors. Each of these systems would aid operators in avoiding collisions. The selection of one of the options depends on the equipment deployed, budget available, and schedule available. Since this effort is not funded for the BWID FY-95 full-scale integrated demonstration, a video intensive system will likely be used with operators communicating among themselves. For the HECS, should it ever be built, the HECS team would recommend a solids model for the collision avoidance system given it is compatible with the ultimate selection of equipment as well as available budget and schedule.

11. Advanced Research Opportunities

As a result of this effort, several advanced research opportunities arose. These are presented here to document these ideas as future projects suitable for BWID support related to an overall integrated HECS. There are five areas of research that are presented below. These include equipment, controls, communication, human-machine interface, and maintenance.

11.1 Equipment Research Opportunities

The gantry system may be augmented by the ability to perform functions in teleoperated, telerobotic, and robotic modes. These functions include swing free control of the hook and any other flexible load supports. Force/position reflection requirements and capabilities should be evaluated in terms of need and productivity enhancements. The desire is a natural/intuitive feel of operation.

Another potential research area is managing communications and power tethers so that the operator is not concerned with modifying operating procedures and paths to accommodate the tethers.

Automation of several excavator operations may lead to productivity improvements. For instance, once a bucket of waste has been retrieved, the placement of the ITM into the conveyance system could be automated.

11.2 Controls Research Opportunities

Sensing issues that may require research would include vector variables (i.e., position, orientation, velocity, acceleration, bearing), soil sensing, force, and other machine health variables.

There seems to be plenty of opportunities to expand machine intelligence capabilities. One example is in path planning for real-time collision avoidance for teleoperations.

Additional work should be looked at in the area of high fidelity force/position reflection technology. The idea of a virtual body-in-the-cab experience should be evaluated in addition to the type of experience that provides for the greatest productivity.

11.3 Communications Research Opportunities

There are also research opportunities for communications system. Tetherless links with tether bandwidth and power capabilities presents a particularly challenging set of research opportunities. Layered networking to accommodate special bandwidth requirements for real-time processes may also need considerable research. Finally, some thought should be given to dynamic sampling and communication rates, presenting some challenges in the area of real-time network communications.

11.4 Human-Machine Interface Research Opportunities

There are several human-machine interface research opportunities. Design interface Option 3 in Section 6 presented information on a virtual reality interface for the controls and displays of the equipment. While some virtual reality widgets are off-the-shelf items, there is still substantial research opportunities in this area. A virtual reality environment could increase productivity and be more intuitive to use than conventional interfaces. Some level of human factors research is required to determine how best to implement augmented telepresence in terms of human performance and reliability. Research issues include methods of representation for telepresence and augmentation displays, methods of interaction, and physical and emotional response to the environment. In addition, some hardware and software would require development specific to the buried waste characterization and retrieval application.

The need for a pointing device in three dimensions or stereo vision enhanced applications could add to operators' effectiveness by providing quality, meaningful video. In addition, the ability to execute visual controls (i.e., pan, tilt, zoom, focus, iris, and roll) coupled with manipulator controls could effect large perceived motions that, in fact, are small. Finally, mixing live video with simulated process graphics using machine vision processing could enhance operator awareness.

11.5 Maintenance Research Opportunities

The final research opportunity area is maintenance. Considerable research thought should be given to remote maintenance functions both in terms of the management and system design. The ability to diagnose the total system and schedule various components for maintenance and/or repair while the remotely operated equipment activities continue uninterrupted is one area that research could focus towards. This would be a broadened application of the System Health Monitoring research currently being performed.

Another largely unexplored maintenance research area is to design for remote/modular maintenance in hazardous and high contamination operations. This could significantly change the way equipment looks or even operates as well as improving the maintainability. The focus of improving maintenance in remote environments could also result in improved equipment reliability. Routine maintenance could be performed remotely or manually. Either method would require design for easy maintenance so that either a robot could perform the maintenance task or a human could maintain the equipment in easier and in a shorter period of time (to reduce exposure and increase productivity).

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Appendix A

Human Engineered Control Station Human Factors Work: Peer Review Comments

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Human Engineered Control Station Human Factors Work: Peer Review Comments

Alvah C. Bittner Jr., Ph.D., CPE

An independent peer review of the Human Engineered Control Station (HECS) Design Concepts work was performed as the means to ensure that work-to-date has been carried out in accord with good human factors practice (in accordance with PO No. C94-170845). As background for this review, information on the Buried Waste Integrated Demonstration (BWID) and the HECS team work assignment was obtained. Specifically, information was obtained from relevant discussions with HECS team personnel, a briefing on the HECS design options, and from review of various documents produced during the HECS work:

- *HECS Requirements* (RAH-07-94), April 1994
- *Functional Analysis*, May 1994
- *Task Analysis*, July 1994
- *Design Concepts*, July 1994.

A standard of "good human factors practice" was employed in this review of the HECS work with quality judged in terms of technical competence, accuracy, and completeness. Addressed in the following sections are five questions regarding (1) HECS work appropriateness, (2) appropriateness of resources consulted, (3) design options meeting of design criteria, (4) future usefulness of the documentation, and (4) reviewer comments and suggestions for future project activity.

The Human Factors Peer Review was performed by Dr. Alvah Bittner of Battelle HARC. Dr. Bittner is a fellow of the Human Factors and Ergonomics Society and has published widely in many areas of human factors and design. He has extensive experience in the development, testing, and evaluation of complex systems.

1. Was the process used in performing the HECS work appropriate for this situation?

The HECS work was performed for a system with a minimum number of molar requirements and limited previous "subsystems integration efforts." In system development efforts, this paucity of requirements leaves the ultimate development of a successful system in question and presents severe challenges for any human factors efforts (Meister, 1986; Bittner, 1993). To meet these challenges, early efforts necessarily involved the development of a plan for developing HECS (RAH-07-94). This well-ordered process plan began with the defining of HECS (operator) requirements and moved through the stages of development using processes appropriate for the development of a conceptual HECS (maintainer issues were not addressed). Unfortunately, the "cycle of design option development" was truncated by the cancellation of participation in a 1995 demonstration, limiting the fulfilling of the original HECS plan. The concluding HECS work was then appropriately turned from the 1995 demonstration toward longer term HECS developments. The process used in performing the HECS work was particularly appropriate for the "constrained and dynamic" conditions under which it was performed.

2. Were appropriate resources consulted for this situation?

Use of subject matter expert (SME) and technical literature resources reflected the paucity of systems requirements information for BWID. Appropriately, in order to assemble subsystem requirements, the primary SMEs consulted represented the separate subsystems being developed (excavator, conveyance, etc.). Subsequently, focus appropriately remained upon these SMEs as the components of their subsystems often changed (necessitating reevaluations of task analyses, etc.). The technical literature consulted also tended to be focused on the general aspects of the human factors issues associated with the various subsystems, as the specifics were often in a state of flux. Without this flux, this reviewer's recommendation would have been for a more comprehensive consultation of the technical literature (e.g., Bittner, Wiker, Bramwell & Kinghorn, 1993). The technical resources consulted were entirely appropriate for the dynamic design situation (albeit others would have been appropriate in most other settings).

3. Do the design concepts options meet the design concept criteria (as presented in the HECS Requirements document)?

The design concepts for the three concept options appear to be generally based on human factors principles and good practice. They, unfortunately, are not as detailed as this reviewer would have preferred, because of the program truncation and its impacts on documentation (see response to documentation question following). The flexibility and evolutionary potential embodied in these design options provided is commendable as a means for both (a) accommodating the current flux in the specifics of subsystem designs, and (b) providing for the subsystem integration issues that only have begun to be addressed.

4. Has work been documented, or is it planned to be documented, in a manner useful to project personnel (e.g., engineers, test designers, human factors specialists) in the future?

The reviewed documentation content and format appears most appropriate for future use by human factors practitioners. Design engineers (as briefly reviewed in Meister, 1986) generally prefer graphic/pictorial formats with minimized text. Test engineers, in contrast, most often like to have the results expressed in the context of briefly stated "major human factors test issues," corresponding subissues, and a delineation of recommended "test methods" to resolve the issues. Neither the design engineer nor test engineer formats is currently planned as part of documentation efforts. This is apparently the case, since the cancellation of participation in a 1995 demonstration both (a) eliminated the opportunity to conduct HF tests, and (b) truncated the fulfilling of the original HECS plan, which had the scheduled development of detailed design plans. HECS documentation for test and design engineers is limited by the current lack of support related to 1995 efforts.

5. Does the reviewer have any other comments or suggestions that may be useful for future project activity?

Three general recommendations can be offered based upon the results of this peer review. These are:

- *HECS related efforts should be included in the 1995 BWID demonstration*—This inclusion would present the opportunity to conduct necessary tests and fulfill the original plan (RAH-07-94) for developing more detailed design documentation. Assessments of operator workload (OWL), perceptual conflict illness, and performance times might be particularly useful for addressing human factors issues, depending on the framework of the BWID demonstration.

- *Development of BWID repair and maintenance (R&M) concepts*—This development should proceed in conjunction with the current operationally orientated developments to ensure that the ultimate BWID is not crippled by an inadequate after-the-fact concept for R&M.

- *Systems integration efforts be incorporated into the current BWID design development process*—It would be useful to begin this process with the use of a group process to begin to comprehensively uncover integration/coordination requirements (e.g., Bittner, 1993).

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Appendix B

Codes and Standards

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Codes and Standards

B-1. FACILITY-STRUCTURAL, ARCHITECTURAL

- Human Factors Handbook.
- DOE-ID Architectural Engineering Standards.

B-2. MECHANICAL SYSTEMS

- DOE Order 6430.1 General Design Criteria.
- ASHRAE STD 62-1989.

B-3. ELECTRICAL SYSTEMS

- National Electric Manufacturers Association (NEMA) requirements.
- NFPA - National Electric Code NFPA 70.
- National Electric Safety Code (NESC).
- Underwriters Laboratories (UL) requirements.
- American Society for Testing and Materials (ASTM) requirements - various product form designations.
- American National Standards Institute (ANSI) requirements - various requirements for materials used in electrical construction.

B-4. INSTRUMENTATION AND DATA ACQUISITION

- Instrument Society of America (ISA) requirements.
- Human Factors Handbook.

B-5. HUMAN FACTORS RELATED

The following documents are interpreted with, and augmented by, human factors principles.

- American National Standards Institute/Human Factors Society ANSI/HFS-100-1988, 1988, *Human Factors Engineering of Visual Display Terminal Work Stations*, February 4.

- U.S. Department of Defense (DOD) MIL-H-46855B, 1979, *Military Specification, Human Engineering Requirements for Military Systems, Equipment and Facilities.*
- DOD-HDBK 743, 1991, *Anthropometry of U.S. Military Personnel*, U.S. Air Force, February.
- DOD-HDBK 763, 1987, *Human Engineering Procedures Guide*, U.S. Air Force, February.
- DOD MIL-STD-1280, 1988, *Keyboard Arrangements*, June.
- DOD MIL-STD-1472D, 1989, *Human Engineering Design Criteria for Military Systems, Equipment, and Facilities*, March.
- DOD MIL-STD-1478, 1991, *Task Performance Analysis*, May.
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- DOE Order 5480.19, 1990, "Conduct of Operations Requirements for DOE Facilities," July 9.
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- National Aeronautics and Space Administration NASA-STD-3000, 1989, *Man-Systems Integration Standards - Revision A*, October.
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- NRC, NUREG/CR-3003, 1983, *Human Engineering Design Considerations for Cathode Ray Tube Generated Displays - Volume II*, July.

B-6. VENTILATION

B-6.1 1991 ASHRAE Chapter 50: Codes and Standards

Ventilation for acceptable indoor air quality - ASHRAE 62-1989.

B-6.2 ASHRAE 62-1989

For office space, the ventilation should be ***20 cfm per person***. This is the highest value and is used for the cooling load calculations.

B-6.3 1981 ASHRAE Fundamentals

Chapter 22, "Ventilation and Infiltration," states: ASHRAE ventilation standard 62-73 (or most current revision) defines the minimum outdoor air supply rates as ***5 cfm per person*** for sedentary activity. This will hold the carbon dioxide level in a space to 0.25% under steady state conditions.

B-6.4 ME Reference Manual

Page 11-6 says the ventilation minimum is ***5 cfm per adult***, but ***7.5 cfm*** is preferred.

B-6.5 DOE Architectural Standards

Section 2.8 states: Ventilation is to follow DOE Order 6430.1A, Uniform Building Code (UBC), and National Fire Protection Agency (NFPA) 90A.

Section 3.2 states: Natural ventilation shall be used wherever safe and practical.

B-6.6 Uniform Building Code

This is a Group A division 3 building (a building that has an assembly room with an occupant load of less than 300, without a legitimate stage). Page 55 of the UBC states: the building must have a mechanically operated ventilation system capable of supplying a minimum of ***5 cfm*** of outside air per occupant with a total circulated of not less than ***15 cfm per occupant*** in all portions of the building during such time as it is occupied.

B-7. OCCUPANT LOADINGS

B-7.1 Uniform Building Code

Page 659 of the UBC states that a conference room requires two exits if there are over 50 people in it.

For a conference room without fixed seats:

> The allowable occupant load is equal to the floor area divided by the occupant load factor (15 for the conference room) so the occupant load is:
>
> (13ft)(13ft)/15 = *11.5 people.*

For a conference room with fixed seating:

> The occupant load is determined by the number of fixed seats installed.
> For rows of seating with an aisle or doorway at one end only, the minimum clear width of 12 in. between rows shall be increased by 0.6 in. for every additional seat beyond seven, not to exceed 22 in. This comes out to about 12 seats.

B-8. WIND

B-8.1 DOE Architectural Engineering Standards

Section 0111-2.2 : Natural phenomena requirements (seismic, wind, tornado, flood) shall be in accordance with DOE Order 5480.28.

Section 0111-5.5 : Wind loads: All structures, systems, components, or portions thereof subject to wind loading shall be designed in accordance with DOE-SDT-1020-94.

B-8.2 Architectural Engineering Standards, Appendix K

Section 3.1 : The unit will be able to withstand a horizontal wind load of 20 lb/ft^2 (9.8 g/cm^2) and a vertical uplift of 19 lb/ft^2 (9.3 g/cm^2).

B-9. EMERGENCY EXITS

Section 0110-3.10 : NFPA 101 "Life Safety Code" shall be used for determining the occupancy classification for means of egress arrangement requirements.

B-10. JACKS, TIE DOWNS, AND CONSTRUCTION

B-10.1 Idaho State Setup Code

Leveling jacks will be placed every 6 ft on center.

B-10.2 Architectural Engineering Standards, Appendix K

Section 3.1: Tie down protection shall be utilized as required by the OC Facility FPE.

Section 3.3: (a) Skirts are required to keep out windblown weeds and trash and shall be provided on all units located at DOE-ID facilities unless otherwise determined by the OC Facility FPE. (b) The underside of trailers and portable structures shall be lined with 18 ga. sheet metal or noncombustible material unless otherwise determined by the OC Facility FPE.

Section 3.2: Ceilings shall be UL listed gypsum or acoustical tile having a flame spread rating of 25 or less and smoked developed rating of 50 or less. Wallboard and surface material shall be UL listed with flame spread rating under 25 and with fuel and smoke developed rating under 50. Insulation shall be noncombustible batts meeting the UL ratings listed above. Minimum "R" factors for batts shall be 11 for walls and 19 for floors and ceilings.

B-11. OTHER CODES, STANDARDS, AND DOE ORDERS

- ASME NQA-1, *Quality Assurance Program Requirements for Nuclear Facilities.*
- *BWID Configuration Management Plan.*
- *BWID Environmental, Health, Safety and Quality Plan.*
- *BWID Program Manual.*
- *BWID Project Management Plan*, EGG-WTD-11224.
- CFR 29 Chapter XVII Part 1910, "Occupational Safety and Health Standards."

- DOE Order 1324.2, "Records Disposition."
- DOE Order 1330.1C (1/12/90), "Computer Software Management."
- DOE Order 1360.3B (11/15/90), "Automatic Data Processing Standards."
- DOE Order 1360.4B (12/31/91), "Scientific and Technical Computer Software."
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- DOE Order 5480.4 (5/15/84), DOE-ID Order 5480.4A, DOE Order 5484.1 Chg 1 (10/17/90), and DOE-ID Order 5484.1B (7/10/91), "Environmental Protection, Safety, and Health Protection Standards and Reporting Requirements."
- DOE Order 5481.1B Chg 1 (5/19/87) and DOE-ID Order 5481.1B (10/18/91), "Safety Analysis and Review System."
- DOE Order 5500.2B Chg 1 (2/27/92), "Emergency Categories, Classes, and Notification and Reporting Requirements."
- DOE Order 5700.6, "Quality Assurance."
- DOE Order 6330.1, "General Design Criteria Manual."
- DOE-ID Order 1330.1C (8/21/86), "Automated Management Information Systems and Data Resources."
- EG&G Idaho, Inc., *Company Procedures Manual.*
- EG&G Idaho, Inc., *Conduct of Operations Manual.*
- EG&G Idaho, Inc., *Engineering Department Standard Practices Manual.*
- EG&G Idaho, Inc., *Quality Manual.*
- EG&G Idaho, Inc., *Safety Manual.*
- National Environmental Policy Act.
- SEN-15-90, National Environmental Policy Act.

Appendix C

Function Analysis for the Buried Waste Integrated Demonstration Program

Appendix C

Function Analysis for the Buried Waste Integrated Demonstration Program

HECS Team

May 11, 1994

The BWID Human Engineered Control Station (HECS) team initiated a function analysis of the BWID system: (1) to start a process of BWID proposed FY-95 integrated demonstration system integration and (2) to begin generating the knowledge needed for development of design options for the HECS. Based on interactions with BWID staff and engineers, available documentation, and logical decomposition, proposed system functions and system parts were identified and listed.

C-1. FUNCTION LIST

Functions identified are those functions that must be performed to retrieve buried waste. These functions are not meant to be in any implied sequence, they are the sum of the tasks, at a higher level of description. Functions are meant to describe *what* is to be accomplished, not *how* it will be accomplished. In fact, most functions have many alternative ways of being accomplished and an important aspect of system integration is to allocate functions to specific system parts. For example, the function of "remove overburden" can be accomplished manually a person with a shovel, a remotely controlled excavator, or by an autonomous robot. The function is the same; the means of accomplishing the function are different.

The attached function list outlines system functions at several different levels. Agreement on this function list is required for further HECS development. This is necessary for system integration, especially because system parts are being designed and developed by different designers. The function analysis detail will be iterative and form the basis for identification and analysis of functions and tasks at finer levels of detail. As BWID integration and HECS development progresses, the analysis of identified tasks will facilitate a more detailed allocation of functions and subfunctions to hardware, software, and staff, and support identification of information and communication requirements for the system. The HECS team will continue to interact with BWID staff and engineers in the continuing function and task analysis, and the development of HECS design options.

C-2. FUNCTION MATRIX

Some system parts have already been associated with listed functions. The attached table is a matrix of system functions versus system parts. The functions listed in the matrix are presented at a high level to facilitate initial discussion relevant to system integration. The level presented in the matrix is assessed as appropriate for initial discussions about the systems integration. The matrix identifies that systems are currently planned to perform each function. "X"s and "?"s are used to identify possible associations between functions and system parts. An "X" suggests that the function is, at least partly, performed by that system part. A "?" identifies uncertainty as to whether a given system part will perform a given function. The "human" column is currently full. Further analysis and decomposition of functions are needed to determine what mix of human and automation is most appropriate to perform the functions in the long run. The matrix is a representation of relationships based on the HECS team's assessment of concepts and information obtained from BWID staff and engineers and available BWID documentation. It is an attempt at representation of current thinking by BWID staff and engineers in terms of BWID functions and systems. In some function rows, there are no "X"s (other than in the human column) which suggests that those functions may not have been fully addressed. In some rows, there are multiple "X"s (or "?"s) suggesting that (1) a decision will have to be made as to which system part to use at a given time, or (2) communication and coordination will be needed. The matrix can serve as a tool for focusing discussion of BWID staff and engineers about the proposed system to facilitate integration of all parts of the system.

C-3. FUNCTION LIST FOR BURIED WASTE RETRIEVAL

Buried Waste Retrieval

- I. Provide management functions
  - A. Provide planning and coordination
    - 1. Appropriate personnel
    - 2. Appropriate equipment
    - 3. Appropriate mode of operation
    - 4. Appropriate sequence of operations
    - 5. Appropriate administrative controls
    - 6. Communications with operating personnel
    - 7. Communications among personnel involved with different BWID systems
    - 8. Test plans
  - B. Provide approval
    - 1. Start
    - 2. Modify
    - 3. Stop
- II. Provide data functions
  - A. Provide data collection/sensors/source of data
    - 1. Continuous
    - 2. Discrete (i.e., sampling)
  - B. Provide for transmission of data
  - C. Provide data storage
  - D. Provide data analysis
    - 1. Real-time
    - 2. Batched
  - E. Provide data display
    - 1. Raw
    - 2. Processed (i.e., analyzed)
- III. Determine site characteristics
  - A. Determine previously known characteristics
  - B. Determine what more you need to know
  - C. Know characteristics of available characterization methods
  - D. Match current site requirements to available method abilities

E. Determine which method(s) to use for site characterization

F. Apply characterization method(s)
   1. Enable characterization method
   2. Describe location of waste in 3 dimensions
   3. Describe nature of waste
   4. Describe amount of waste
   5. Describe important geometries of waste

G. Decide site characterization is sufficient

IV. Determine characteristics of current digface
   A. Define current digface
   B. Decide what you need to know about current digface
   C. Know characteristics of available characterization methods
   D. Match current dig-face requirements to available method abilities
   E. Determine which method(s) to use for digface characterization
   F. Apply characterization method(s)
      1. Enable characterization method
      2. Describe location of waste in 3 dimensions
      3. Describe nature of waste
      4. Describe amount of waste
      5. Describe important geometries of waste
   G. Decide digface characterization is sufficient

V. Remove overburden
   A. Know which overburden characteristics must be known before removal
   B. Review known overburden characteristics and determine what characteristics still need to be discovered
   C. Perform further characterization, as needed
   D. Decide which method will be used to remove overburden
   E. Apply method to remove overburden
      1. Enable removal method
      2. Select the portion of overburden to be removed
      3. Remove the selected portion of the overburden from its original position
      4. Screen/sort the overburden
      5. Transport the selected portion of the overburden away
   F. Decide overburden removal is complete

VI. Perform hot spot retrieval
   A. Select the next hot spot according to excavation plan
   B. Determine what more you need to know for selected hot spot
   C. Perform further characterization, as needed
   D. Decide which method will be used to retrieve hot spot
   E. Apply method to retrieve hot spot
      1. Determine method to be used for removing hot spot material
      2. Plan movement of material to be removed to next resting point
      3. Apply methods for removing hot spot material
         a) Enable methods for removing materials
         b) Manipulate methods for removing materials
         c) Place retrieved objects in separate waste streams
         d) Determine and record nature of removed material

4. Determine need for shoring sides
5. Determine method for shoring sides
6. Shore sides
   a) Enable shoring method
   b) Manipulate shoring method
7. Determine need for contamination control
8. Determine method to be used for contamination control
9. Apply contamination control
   a) Enable contamination control method
   b) Manipulate contamination control method
10. Determine need for sizing
11. Determine method for sizing
12. Apply chosen sizing method
   a) Enable sizing methodology
   b) Manipulate object into position for sizing
   c) Manipulate sizing methodology
   d) Manipulate object(s) to next resting point
13. Move removed hot spot material to next resting point

F. Determine hot spot retrieval is complete
G. Transport in filler dirt and fill hole

VII. Perform full-scale retrieval

A. Select area to begin full-scale retrieval according to excavation plan
B. Determine if further characterization details are required
C. Perform further characterization, as needed
D. Remove material from selected area

1. Determine method to be used for removing material
2. Plan movement of material to be removed to next resting point
3. Apply methods for removing hot spot material
   a) Enable methods for removing materials
   b) Manipulate methods for removing materials
   c) Determine and record nature of removed material
4. Determine need for shoring sides
5. Determine method for shoring sides
6. Shore sides
   a) Enable shoring method
   b) Manipulate shoring method
7. Determine need for contamination control
8. Determine method to be used for contamination control
9. Apply contamination control
   a) Enable contamination control method
   b) Manipulate contamination control method
10. Determine need for sizing
11. Determine method for sizing
12. Apply chosen sizing method
   a) Enable sizing methodology
   b) Manipulate object into position for sizing

c) Manipulate sizing methodology
d) Manipulate object(s) to next resting point

13. Move removed material to next resting point

E. Determine full-scale retrieval is complete

VIII. Monitor system functions

A. Monitor characterization
B. Monitor other environmental conditions
C. Monitor equipment condition
D. Monitor operator performance
E. Monitor automated performance
F. Monitor data
G. Monitor software performance

IX. Perform maintenance

A. Decontaminate material/equipment
B. Preventive/routine maintenance
C. Unscheduled maintenance

Initial Matrix of Buried Waste Retrieval Functions With Current BWID Equipment

This mapping is not meant to be a final functional allocation, but rather a description of current expectations. Agreement on this matrix will facilitate system integration.

	FUNCTIONS	human	HECS	multiple manipulators	sizing	dig-face character-ization	grouting	misting	fixants CCU	SONSUB end effector	vacuum	tools	interfer-ometer	GPR	hoist	excava-tor	convey-ance	SCS	system health	build-ing	dust samplers
I	provide management functions																				
A	provide planning and coordination	x																			
B	provide approval	x																			
II	provide data functions																				
A	provide data collection /sensors /source of data	x		x	?	x	?	?	?	?	x	?	x	x	x	x	x	?	x	x	x
B	provide for transmission of data	x	x	x	x	x	?	?	?	?	x	?	x	x	x	x	x	x	x	x	x
C	provide data storage	x	x													x		x	x		
D	provide data analysis	x	x			?							?	?		x	?	x	x		
E	provide data display	x	x																		
III	determine site characteristics																				
A	determine previously known characteristics	x																			
B	determine what more you need to know	x																			
C	know characteristics of available characterization methods	x																			
D	match current site requirements to available method abilities	x																			
E	determine which method(s) to use for site characterization	x																			
F	apply characterization method(s)	x	x			x							x	x							
G	decide site characterization is sufficient	x																			
IV	determine characteristics of current dig-face																				

	FUNCTIONS	human	HECS	multiple manipulators	sizing	dig-face character-ization	grouting	misting	fixants CCU	SONSUB end effector	vacuum	tools	interfer-ometer	GPR	hoist	excava-tor	convey-ance	SCS	system health	build-ing	dust samplers
A	define current dig-face	x														?					
B	decide what you need to know about current dig-face	x														x					
C	know characteristics of available characterization methods	x																			
D	match current dig-face requirements to available method abilities	x																			
E	determine which method(s) to use for dig-face characterization	x																			
F	apply characterization method(s)	x	x	x		x						?	?	x							
G	decide dig-face characterization is sufficient	x														x					

	FUNCTIONS	human	HECS	multiple manipulators	sizing	dig-face character-ization	grouting	misting	fixants CCU	SONSUB end effector	vacuum	tools	interfer-ometer	GPR	hoist	excava-tor	convey-ance	SCS	system health	build-ing	dust samplers
V	remove overburden																				
A	know which overburden characteristics must be known before removal	x																			
B	review known overburden characteristics and determine what characteristics still need to be discovered	x																			
C	perform further characterization, as needed	x	x	x		x						?	x	x				x			
D	decide which method will be used to remove overburden	x																			
E	apply method to remove overburden	x	x	x				x	?	x	x	x			?		x	x		x	
F	decide overburden removal is complete	x																			
VI	perform hot spot retrieval																				
A	select the next hot spot according to excavation plan	x																			
B	determine what more you need to know for selected hot spot	x																			
C	perform further characterization, as needed	x	x	x		x						?	x	x				x			
D	decide which method will be used to retrieve hot spot	x																			
E	apply method to retrieve hot spot	x	x	x	x		x	x	x		x	x			?		x	x		x	
F	determine hot spot retrieval is complete	x																			

	FUNCTIONS	human	HECS	multiple manipulators	sizing	dig-face character -ization	grouting	misting	fixants CCU	SONSUB end effector	vacuum	tools	interfer-ometer	GPR	hoist	excava-tor	convey-ance	SCS	system health	build-ing	dust samplers
VIII	monitor system functions																				
A	monitor characterization	x	x															x			
B	monitor other environmental conditions	x	x														?	x		?	x
C	monitor equipment condition	x	x														x	x	x		
D	monitor operator performance	x	?															?			
E	monitor automated performance	x	x															x			
F	monitor data	x	x															x			
G	monitor software performance	x	x															x			
IX	perform maintenance																				
A	preventive/routine maintenance	x	x	x								x			x		x	x	x	x	
B	unscheduled maintenance	x	x	x								x			x		x	x	x	x	x

	FUNCTIONS	human	HECS	multiple manipulators	sizing	dig-face character-ization	grouting	misting	fixants CCU	SONSUB end effector	vacuum	tools	interfer-ometer	GPR	hoist	excava-tor	convey-ance	SCS	system health	build-ing	dust samplers
VII	perform full scale retrieval																				
A	select area to begin full scale retrieval according to excavation plan	x																			
B	determine if further characterization details are required	x														x					
C	perform further characterization, as needed	x	x	x		x												x			
D	remove material from selected area	x	x	x	x			x	x		x	x			?	x	x	x		x	
E	determine full scale retrieval is complete	x																			

Appendix D

Task Description and Analysis Forms

Appendix D

Task Description and Analysis Forms

Instructions/Explanations for the BWID Task Analysis Form

1. **General information concerning this form:** This form is designed to collect the pertinent task information for BWID. The main tasks are listed on the form "BWID Tasks" and the primary contacts are listed on the "BWID Task Contacts." It is expected that there will be tasks that are not listed on the "BWID Tasks" form. Also, it is expected that the person listed as "Primary Contact" may direct you to someone else. The tasks listed on the "BWID Tasks" form are at a high level. The tasks are expected to have subtasks and each subtask will have several elements. At the task level, the Element Information and Human Error Information pages would be completed for the subtasks. At the subtask level, the Element Information and Human Error Information pages would be completed for the elements.

2. **Date:** Date the interview is performed.

3. **Task Identifier:** Number is assigned by you. You will be discussing several tasks and subtasks with each subject matter expert (SME). This number refers to which task or subtask you are discussing with the SME. We will assign the appropriate sequence number when we enter this task or subtask into the database.

4. **Interviewer:** You are the interviewer. Write your full name not just your initials.

5. **SME:** Stands for Subject Matter Expert. This would be the person you are interviewing. Write the person's name, not just initials.

6. **Prior Task Identifiers:** Task or subtask number(s) that the operator/system completes immediately before initiating this task or subtask. Again, you assign this number while discussing the task or subtask with the SME. The appropriate sequence number will be assigned upon entering the data into the database. If the prior task or subtask is outside the subject area that you are investigating with the SME, write out a description and the correct number will be assigned when the information is entered into the database.

7. **Concurrent Task Identifiers:** Task or subtask number(s) that the operator/system performs while performing this task or subtask. Again, you assign this number while discussing the task or subtask with the SME. The appropriate sequence number will be assigned upon entering the data into the database. If the prior task or subtask is outside the subject area that you are investigating with the SME, write out a description and the correct number will be assigned when the information is entered into the database.

8. **Level of Synergism with Concurrent Task:** Amount of synergism or dependence between the task or subtask you are investigating and the concurrent task or subtask. On the scale, "1" reflects no synergism, and "5" reflects high synergism.

9. **Post-task Identifiers:** Task or subtask number(s) that the operator/system initiates immediately after completing this task or subtask. Again, you assign this number while discussing the task or subtask with the SME. The appropriate sequence number will be assigned upon entering the data into the database. If the prior task or subtask is outside the subject area that you are investigating with the SME, write out a description and the correct number will be assigned when the information is entered into the database.

10. **Task Description:** Textual description that you fill out while interviewing the SME. Describe the task or subtask with as much detail as possible. Do not describe information found elsewhere in this form. This block is designed to give a reviewer an overview of this task or subtask.

11. **Task Purpose:** Textual information concerning the purpose of this task or subtask that you fill out while interviewing the SME. Describe the purpose of the task or subtask with as much detail as possible. Do not describe information found elsewhere in this form. This block is designed to give a reviewer an overview of the purpose of the task or subtask.

12. **Duration (minutes):** Amount of time, in minutes, that the operator is expected to take to complete this task or subtask.

13. **System Time Available (minutes):** Amount of time, in minutes, the system allows for the completion of this task or subtask. For example, if the requirements are to move 100 cubic yards per a 10 hour day, the system must move 10 cubic yards per hour. If the conveyance system can carry 1 cubic yard, then the conveyance system must make 10 full trips per hour. This means that the system time available would be 6 minutes per trip.

14. **Task Difficulty:** Subjective expected level of difficulty that the operator/system will experience while completing this task or subtask. This can refer to physical and/or mental difficulty and can be measured as a combination of time, effort, or stress. On the scale, "1" means an easy task or subtask, while "5" means a difficult task or subtask.

15. **Task Importance:** Importance to the system that the task or subtask is completed correctly within the time allotted. Some tasks or subtasks may not be as important as others in accomplishing the goals of the system. On the scale, "1" means a relatively unimportant task or subtask, while "5" means a highly important task or subtask.

16. **Task Frequency:** Amount of times this task or subtask must be completed per hour. This is a numerical input.

17. **Task Relative Frequency:** The number from "Task Frequency" may be insufficient to understand whether this frequency is strenuous. "Task Relative Frequency" is meant to compare the strenuous nature of the frequency of this task or subtask to other tasks or subtasks. For example, requiring an operator to complete a short log form 20 times per hour might be less strenuous than expecting the operator to perform a digface characterization 10 times per hour. On the scale, "1" means a relatively low frequency task or subtask, while "5" means a relatively high frequency task or subtask.

18. **Knowledge Required:** Level of knowledge the operator is expected to have to perform this task or subtask. On the scale, "1" means an extremely low level of knowledge, while "5" means a relatively high level of knowledge required.

19. **Experience Required:** Level of experience the operator is required to have to perform this task or subtask. On the scale, "1" means an extremely low level of experience, while "5" means a relatively high level of experience required.

20. **Notes:** Space provided to allow you to make comments to explain your responses indicated in the form, as necessary. The space also is provided for the collection of information not indicated on this form.

21. **Element Identifier (number):** Number is assigned by you. You will be discussing several subtasks and elements with each SME. This number refers to which subtask or element you are discussing with the SME. We will assign the appropriate sequence number when we enter this subtask or element into the database.

22. **Location Code:** Number to the right of the "Location Codes" underneath this blank. If the appropriate choice is "5," then specify the location.

23. **Performer Code:** Number to the right of the "Performer Codes" underneath this blank. If the appropriate choice is "6," then specify the title of the performer.

24. **Element Description:** Textual description that you fill out while interviewing the SME. Describe the subtask or element with as much detail as possible. Do not describe information found elsewhere in this form. This block is designed to give a reviewer an overview of this subtask or element. When completing of this portion of the form, use action-oriented words provided in the action verb list.

25. **Initiating Cue:** Action of the operator/system that tells the operator/system to perform this element or subtask. For example, an annunciator light or sound or a position of the equipment may act as cues.

26. **Terminating Cue:** Action of the operator/system that tells the operator/system that actions within this element or subtask are complete. For example, an annunciator light or sound or a position of the equipment may act as cues.

27. **Equipment Used to Perform This Element:** Equipment being actively or passively used during the completion of this subtask or element. For example, the gantry crane controls will be actively used and visual displays will be passively used.

28. **Information Input:** Information required by the operator/system during the completion of this subtask or element.

29. **Information Output:** Information that the operator/system generates and outputs during the completion of this subtask or element.

30. **Material Input:** Materials required by the operator/system during the completion of this subtask or element..

31. **Material Output:** Material that the operator/system generates and outputs during the completion of this subtask or element.

32. **Feedback Indicators:** System responses that indicate the operator's the level of performance. For example, those system responses that tell the operator the direction of movement, amount of force being applied, etc.

33. **Performance Indicators:** System responses that tell the operator whether they are performing correctly. For example, those system responses including annunciators that would tell the operator not exceed position or weight setpoints.

34. **Success Indicators:** System responses that tell the operators that they have completed the task successfully. For example, those system responses that tell the operator the information has collected or the SONSUB lid effector is closed.

35. **Failure Indicators:** System responses that tell the operators that they completed the task unsuccessfully. For example, those system responses that would inform the operator the lid has been left open or the grappling hook is not secured.

36. **Error Description:** Description of the human actions that show human errors. The wording should be action oriented and use the provided action verb list. It is possible that there will be several error modes for each subtask or element.

37. **System Impact:** Impact the human error will have on the system. This could include consequences or a description of the impact boundaries. For example, a dropped cask could rupture and contaminate the entire area under the tent enclosure.

38. **Severity:** This scale is used to indicate the severity of the consequences/impact of the error mode. On the scale, "1" extremely low severity, and "5" is extremely high severity.

39. **Frequency:** This scale is used to indicate the frequency of occurrence of the error mode. On the scale, "1" extremely low frequency, and "5" is extremely high frequency.

Date: ____________

Task Identifier (number): ____________ Interviewer: ____________ SME: ____________

Prior Task Identifiers (Number)	Concurrent Task Identifiers (Number)	Level of Synergism with Concurrent Task	Post Task Identifiers (Number)
		1 2 3 4 5	
		1 2 3 4 5	
		1 2 3 4 5	
		1 2 3 4 5	
		1 2 3 4 5	

Task Description:

Task Purpose:

Duration (minutes):

System Time Available (minutes):

Task Difficulty: 1 2 3 4 5

Task Importance: 1 2 3 4 5

Task Frequency (repetitions per hour):

Task Relative Frequency: 1 2 3 4 5

Knowledge Required: 1 2 3 4 5

Experience Required: 1 2 3 4 5

Notes:

Element Identifier (number): ____________ Location Code: ____________ Performer Code: ____________

Location Codes: 1-HECS 2-Inside Enclosure 3-Inside Airlock 4-Outside Enclosures 5-Other (Specify)

Performer Codes: 1-Heavy Equipment Operator 2-Automation 3-Technician 4-HECS Operator 5-Supervisor 6-Other (Specify)

Element description:

Initiating cue:

Terminating cue:

Equipment used to perform this element:

Information input:

Information output:

Material input:

Material output:

Feedback indicators:

Performance indicators:

Success indicators:

Failure indicators:

Human Error Information

Error Description:

System impact:
Severity: 1 2 3 4 5 Frequency: 1 2 3 4 5

Error Description:

System impact:
Severity: 1 2 3 4 5 Frequency: 1 2 3 4 5

Error Description:

System impact:
Severity: 1 2 3 4 5 Frequency: 1 2 3 4 5

Error Description:

System impact:
Severity: 1 2 3 4 5 Frequency: 1 2 3 4 5

Error Description:

System impact:
Severity: 1 2 3 4 5 Frequency: 1 2 3 4 5

Error Description:

System impact:
Severity: 1 2 3 4 5 Frequency: 1 2 3 4 5

Appendix E

BWID Tasks

Appendix E

BWID Tasks

The annotations (HF) and (SME) in this task list refer respectively to tasks developed by HECS human factors personnel and tasks reported by BWID subsystem experts

1. General use of gantry crane (generalized gantry crane task generated largely by HF)

- It is anticipated that moving the crane from the home position to the home position will take 10 to 15 minutes plus the time to perform excavation or other task.

- It is anticipated that the gantry crane will be used for selective retrieval using vacuuming for 25 to 30% of the time.

- The use of a remotely operated gantry crane is intended to aid in the safe location and selective retrieval of hazardous waste. A specific area for tool storage will be used. There should be a simulation of the location of all equipment available to crane operators. Real-time video should be used for confirmation of crane activities. Crane operations should be handled by a primary and a secondary operator. Ideally, software should be used for much of the control of the crane and its associated tools. Frequently repeated actions (e.g., going to the tool storage area) will be "taught" to the crane so that the operator can issue a command and the action will be performed automatically. Some operations will be teleoperated. Ideally, the system should be simple enough to operate that a high school graduate could learn to operate it in a matter of hours.

1.1 Prepare to operate crane (HF)
- 1.1.1 Acquire and review site work permit (SME)
- 1.1.2 Determine need to use crane for digface characterization, contamination control, waste retrieval, waste removal etc. (HF)
  - 1.1.2.1 Characterize current situation (HF)
  - 1.1.2.2 Anticipate future situation Next function that must be performed (e.g., contamination control, digface characterization) (HF)
- 1.1.3 Know types of tools available (HF)
- 1.1.4 Know uses of available tools (HF)
- 1.1.5 Match available tools with current/future situation (HF)
- 1.1.6 Decide appropriate tool for current/future situation (HF)
  - 1.1.6.1 Choose sensor/tool for digface characterization (see task 1.1) (HF)
  - 1.1.6.2 Choose mode/tool of contamination control (HF)
  - 1.1.6.3 Choose technique/tool for waste retrieval (HF)
  - 1.1.6.4 Choose vacuum system (see task 1.7)
  - 1.1.6.5 Choose soil buster
  - 1.1.6.6 Choose technique/tool for waste removal
  - 1.1.6.7 Choose vacuum system (see task 1.7)
  - 1.1.6.8 Choose other tool

1.1.7 Know location of available tools

1.1.8 Coordinate planned crane use with other pieces of equipment

1.1.8.1 Ensure collision avoidance with (conveyance, excavator)

1.1.8.2 Plan interactions with other pieces of equipment (conveyance, excavator)

1.2 Start up crane

1.2.1 Perform start up sequence on crane (SME)

1.2.2 Perform preoperation check (SME)

1.2.2.1 Of crane (SME)

1.2.2.2 Of HECS equipment (SME)

1.3 Operate crane (HF)

1.3.1 Move gantry crane with manipulators and hoist to "front door" of tool storage (SME)

- How does operator ensure that there will be no collision with other equipment? Needs position sensors on all equipment and appropriate display/alarm/control software.

1.3.1.1 Issue command to move crane to "front door" of storage area (HF)

1.3.1.2 Confirm command to move to "front door" of storage area has been received (HF)

1.3.1.3 Monitor progress toward "front door" of storage area (HF)

1.3.1.4 Monitor control console information to determine when crane is at "front door" of storage area (HF)

1.3.1.5 Verify crane is at "front door" of storage area using feedback from remote vision (HF)

1.3.2 Position manipulator arm within storage area to attach desired tool (SME)

1.3.2.1 Issue command to move manipulator arm to position to interface with desired tool (HF)

1.3.2.2 Confirm command to move manipulator arm to position to interface with desired tool has been received (HF)

1.3.2.3 Monitor progress toward desired tool (HF)

1.3.2.4 Monitor control console information to determine when manipulator arm is in position to interface with desired tool (HF)

1.3.2.5 Verify manipulator arm is in position to interface with desired tool using feedback from remote vision (HF)

1.3.3 Interface desired tool to manipulator arm (this task may involve not only interfacing the manipulator with some type of "T-handle" on the desired tool, but also attachment of necessary power cords, hoses, etc.) (SME)

1.3.3.1 Issue command to interface manipulator arm and desired tool (HF)

1.3.3.2 Confirm command to interface manipulator arm and desired tool has been received (HF)

1.3.3.3 Monitor progress of interface operation with desired tool (HF)

1.3.3.4 Monitor control console information to determine when interface operation with desired tool has been completed (HF)

1.3.3.5 Verify completion of interface operation between manipulator arm and desired tool using feedback from remote vision (HF)

1.3.4 Perform status check with newly interfaced tool to ensure that it is operational (SME)

1.3.5 Move crane with manipulator arm and interfaced tool to desired location (SME)

- 1.3.5.1 Issue command for crane to move to a specific location (HF)
- 1.3.5.2 Confirm command to move to a specific location has been received (HF)
- 1.3.5.3 Monitor progress of crane toward desired location (HF)
- 1.3.5.4 Monitor control console information to determine when movement of crane has been completed (HF)

1.3.6 Verify crane is in desired location using feedback from remote vision (HF)

1.3.7 Enable desired tool (steps needed for this task will vary according to the tool used) (HF) (see other task analyses for what information is available)

1.3.8 Operate desired tool (procedure will vary according to the tool used) (HF) (see other task analyses for what information is available)

1.3.9 Move crane with manipulator arms and interfaced tool to "front door" of tool storage area. (SME)

- 1.3.9.1 Issue command for crane to move to "front door" of tool storage area (HF)
- 1.3.9.2 Confirm command to move to "front door" of tool storage area has been received (HF)
- 1.3.9.3 Monitor progress of crane toward "front door" of tool storage area (HF)
- 1.3.9.4 Monitor control console information to determine when crane is at "front door" of tool storage area. (HF)
- 1.3.9.5 Verify crane is at "front door" of tool storage area using feedback from remote vision (HF)

1.3.10 Position manipulator arms for detaching currently used tool (SME)

- 1.3.10.1 Issue command for crane to move to particular location (HF)
- 1.3.10.2 Confirm command to move to some particular location has been received (HF)
- 1.3.10.3 Monitor progress of crane toward tool desired location (HF)
- 1.3.10.4 Monitor control console information to determine when crane has arrived at desired location.
- 1.3.10.5 Verify crane is in desired location using feedback from remote vision (HF)

1.3.11 Detach tool and replace it in the tool storage area (SME)

- 1.3.11.1 Issue command to detach tool (and any associated power supply, hoses etc.) and replace properly in tool storage area (HF)
- 1.3.11.2 Confirm command to detach and replace tool has been received (HF)
- 1.3.11.3 Monitor progress of detaching and replacing tool (HF)
- 1.3.11.4 Monitor control console information to determine when tool has been detached and replaced (HF)
- 1.3.11.5 Verify tool has been detached and replaced using feedback from remote vision (HF)

1.3.12 Move crane to "front door" of tool storage area (SME)

- 1.3.12.1 Issue command move crane to "front door" of tool storage area (HF)

1.3.12.2 Confirm command to move crane to "front door" of tool storage area has been received (HF)

1.3.12.3 Monitor progress of crane toward "front door" of tool storage area (HF)

1.3.12.4 Monitor control console information to determine when crane has reached "front door" of tool storage area (HF)

1.3.12.5 Verify crane has reached "front door" of tool storage area using feedback from remote vision (HF)

1.3.13 Move crane to its "home" location (return it to its standard position) (SME)

1.3.13.1 Issue command move to "home" the crane (HF)

1.3.13.2 Confirm command to "home" the crane has been received (HF)

1.3.13.3 Monitor progress of crane toward "home" (HF)

1.3.13.4 Monitor control console information to determine when crane has reached "home" (HF)

1.3.13.5 Verify crane has reached "home" using feedback from remote vision (HF)

1.3.14 Perform shut down sequence (SME)

1.3.15 Perform preventive/routine maintenance of crane, manipulator arms, and tools (SME)

- Logical decomposition of crane operation suggests some maintenance will be needed, but more details are needed.

1.3.16 Most likely to least likely sources of human error

1.3.16.1 Move crane to excavation location/return crane to tool storage area

1.3.16.2 Attach tool to manipulator arms/detach tool and replace it in tool storage area

1.3.16.3 Enable attached tool

1.3.16.4 Disable attached tool (add to above)

1.3.16.5 Position crane in storage area prior to attaching tool/position crane in storage area prior to detaching tool

1.3.16.6 Move crane to tool storage area prior to attaching tool/move crane to tool storage area prior to detaching tool

2.0 Gantry crane with manipulators

2.1 Digface characterization system (sensors, crane, manipulators)

- How do you keep from contaminating the different types of waste with the previously moved waste (e.g., move radioactive first, then hazardous would result in mixed waste if the excavator or conveyance are not cleaned first). How do you avoid contaminating clean soil with waste?
- How do you measure ppm in air when the diesel excavator is putting pollutants into the air? How do you detect metal when the gantry crane, excavator, etc. are made of metal? The magnetic sensor can sense large objects far away or small objects close, and it might be difficult to tell them apart. Might be able to do it with multiple scans, but how do you separate out a small barrel from all the metal in the building and the equipment? Might be able to do multiple scans and present a volume display that would zero in on the item.
- How do data gathered using ground penetrating radar, interferometer, and dust sampling device correlate with digface characteristic data? Do they? Should they? Is it redundant? Useful redundancy?

- After quick scan, how do you return to a spot for a detailed scan? How do you retrieve the coordinates?
- Part of the digface characterization is to identify waste to aid in safety and separation.
- Safety: chemicals, compressed air, volatile gases, volatile organic compounds, carcinogens, etc. Some of these might be in containers under pressure (e.g., an acetylene bottle which is contaminated) and cause explosions, launch dust, or become projectiles. If this happens, then there is now mixed waste all over.
- Separation: There is clean dirt in addition to hazardous, radioactive (high, low, and transuranic), and mixed waste. The hazardous waste can be of several forms and will need to be put into separate piles.
- Sensitivity of sensors differs. Some have very low sensitivity and some are highly sensitive. Some are directional and some collect data from any direction. (Gamma and neutron sensors are sensitive to radiation from all directions.) Operator must understand this in order to interpret information. The operator must not only understand the sensors and how to read them, but what the information means. VOC sensors give a composite of all compounds that are there, not what individual compounds are there. Will there be access to individual sensors for measuring specific compounds? If so, need to have some idea of what these compounds will be in order to know what sensor to use. If VOC sensor finds something, then a person will have to go in and take a sample for further analysis. Sensors can only sense in the top 2 to 3 ft of soil. What about things further down when digging? Will a sensor record the same information if (1) the object is 2 feet from the sensor but covered by 1 foot of dirt or (2) the object is 2 feet from the sensor but covered by 2 inches of dirt. What about jumbled, mangled metal, where the metal sensor will not give real details about what is buried?
- Excavation and remediation cannot be done to the same level of detail as the sensors can identify. Can identify and locate hot spot (although "hot spot" has not been defined), but currently no known way to carefully excavate hot spot. Will contaminate everything else in the process. A lot of the waste treatment processes have not yet been defined, and it does not seem right to be characterizing the waste when the process to store it has not been developed. We need to know the process input requirements before characterizing the waste, and those have not been defined yet.
- The top surface of a buried object can be determined, but the depth of the object must be estimated. This is done by applying a straight edge and a pencil to a map. Simple automation under development.
- There will be times during the process of digface characterization that operations are turned over to another task/function. This could fall between almost any two steps (e.g., "enough data has been collected, now lets dig").

2.1.1 Calibrate/check calibration

- Should calibration be checked first thing in the morning for all sensors? Or should it be done just before the sensor is needed? Before or after attaching to crane? Does movement affect the sensor calibration? What if the sensor needs to be calibrated? Who does this? How? How often do they need to be calibrated? Should do a calibration test at least once a day. Need to set up a calibration area with known characteristics for the calibration test. Where will the calibration be done? How do you keep the calibration standards/calibration area from being contaminated? How operate? Calibration is currently designed to be done by a person. How is this going to be done in the remote environment?

2.1.1.1 Move sensors to calibration station (HF)

2.1.1.2 Perform calibration (HF)

2.1.2 Obtain and analyze data needed to define area to be scanned (HF)

- Data from previous scans?
- Information to/from characterization team?
- Information to/from management?
- A supervisor or planner will probably do this.

2.1.3 Define current digface area

- The digface is constantly being redefined as data are being collected.
- How is the time going to be used? Which task gets use of the gantry crane during what time? Will digface characterization be done on one half of the pit, then excavation on that portion while digface characterization is performed on the other half? Will digface characterization be done at night and excavation during the day? Cannot do both at same position at same time. Will the characterization team have a certain amount of time at the crane (e.g., x amount of time and x amount of area would dictate whether quick or detailed scan could be performed)?

2.1.3.1 Define topography (HF)

2.1.3.2 Define perimeter (HF)

2.1.4 Decide digface characteristics needed

2.1.4.1 Define level of detail needed (HF)

2.1.4.2 Define sensor group needed (HF)

- Hazardous and radiological sensor groups cannot be used at the same time because of weight (e.g., hazardous group weighs almost 200 lbs by itself). Therefore, two scans must be done to obtain all information.

2.1.5 Plan/define scan

- Quick scan should be done as one continuous scan. If go back and forth between quick and detailed, then the data would be hard to interpret.

2.1.5.1 Determine orientation (horizontal, vertical, or angled)

- Currently, sensors cannot follow the topography. It is possible to record the distance of the surface from the sensor, but this would require the operator to interpolate when viewing displays. Orientation of the sensors will probably be determined by the operator based on experience and topography.

2.1.5.2 Determine scan width

2.1.5.3 Determine scan rate (time available will influence scan rate)

2.1.5.4 Determine whether automatic or manual scan is to be used

- Need a manual override to the automatic mode.

2.1.5.5 Determine distance between sensors and digface

- Sensors should be as close to the surface as possible for measurement of radioactivity and volatile gases, especially for something like a leaky barrel that is not giving off a lot of volatile gases. A lot of this work will be done manually.

2.1.6 Transmit/give scanning plan to digface and gantry crane operator

- How will this be done? Verbally? On paper? By computer? Are the people defining the plan in the same room as the crane operator?

2.1.7 Enable digface characterization equipment

- How is all of this equipment monitored? What kind of feedback is given to the operator?

2.1.7.1 Move manipulator arm to sensor storage area (HF/SME)

2.1.7.2 Position manipulator arm over appropriate sensor (HF/SME)

2.1.7.3 Attach sensor group to manipulator arm (HF/SME)

- It is expected that only one of the manipulator arms will be required for digface characterization.

2.1.7.3.1 Hazardous group (gamma, neutron, volatile organic compounds)

2.1.7.3.2 Geophysical group (magnetic, soil conductivity, metal sensors)

2.1.7.4 Select mode of operation (automatic or manual) (HF)

- Automatic mode can have the beginning coordinates and the crane will automatically go to those coordinates from wherever it is.

2.1.7.5 Program/select orientation (horizontal, vertical, or angled, for automatic or manual mode) (HF)

2.1.7.6 Program/select scan width (automatic or manual mode) (HF)

2.1.7.7 Program/enter start coordinates (automatic or manual mode) (HF)

2.1.7.8 Program/enter scan rate (time available will influence scan rate, automatic or manual mode) (HF)

- What is the maximum scan rate for each sensor/sensor group? Can this be programmed into the operations software so that it never has to be entered? Could sensor selection automatically dictate scan rate?

2.1.7.9 Program scan pattern (automatic mode only) (HF)

2.1.7.10 program end point (automatic mode only) (HF)

2.1.8 Enable digface data collection system (must be coordinated simultaneously with enabling digface characterization equipment) (HF)

- How do the sensors get turned on? Physically, in which case the crane operator might do it? Or when the computer begins collecting data, in which case the characterization team would do it? Or is it automatically done when the characterization team initializes the computer system?

2.1.8.1 Select sensor group to record (HF)

2.1.8.2 Set display windows (if setup allows operators to select what they want to look at) (HF)

- Currently, all displays will use the units of the sensor, and these are the units that the characterization team is used to.

- Will probably use PV Wave as the software to generate plots.

2.1.8.2.1 Plan view

- It has been suggested that a plan view of the entire pit and equipment locations (reference schematic) be available to operators at all times.

2.1.8.2.2 Strip plot

- Characterization team will probably need some strip chart-type plots in addition to the surface plots. These would be displayed for each single pass of the sensor and would help ensure data quality. In addition, contour plots can be easily obtained. Maybe this would be something that the operator could bring up at will in a Windows environment.

2.1.8.2.3 Surface plots (sensor data relative to position)

2.1.8.2.4 Contour plots

2.1.8.2.5 Data channels (data types)

- All data are tagged with time and location information (e.g., digface coordinates).

2.1.8.2.5.1 Hazardous group

2.1.8.2.5.1.1 Gamma

2.1.8.2.5.1.2 Neutron

2.1.8.2.5.1.3 Temperature

2.1.8.2.5.1.4 Volatile organics (ppm)

2.1.8.2.5.1.5 Digface-to-sensor distance

2.1.8.2.5.2 Geophysical group

2.1.8.2.5.2.1 Temperature

2.1.8.2.5.2.2 Dig-face-to-sensor distance

2.1.8.2.5.2.3 Soil conductivity

2.1.8.2.5.2.4 Magnetic field gradient

2.1.8.2.5.2.5 Magnetic field magnitude

2.1.8.2.5.2.6 Metal detector output

- What output will be available from the metal sensor? It has not been selected yet. Metal detector uses a magnetic field. Will it interfere with the magnetic detector? Will shoring interfere?

2.1.9 Perform scan

2.1.9.1 Issue command to start scanning operation and data collection (HF)

- How do the crane operator and characterization team coordinate "starting"? Does one start a system that automatically starts the other system? Are these electronically connected? When the scan is started by the crane operator, does this automatically start the data collection if the characterization team has initialized the equipment?
- Automatic mode moves crane to start point of scan and follows programmed scanning pattern (HF)

- Manual mode moves crane to start point (HF)

2.1.9.2 Move manipulator arm/crane through scan path (manual mode only) (HF)

2.1.9.3 Display/monitor/save real-time data to characterization team. (HF)

- Will displays automatically show what is being scanned? Will only those sensors in operation be shown? Will operators select which ones they want to look at? Will all displays be on one monitor? Will a different monitor be dedicated to each sensor group (radiation/hazard and geophysical)? Will all of this operate in a Windows environment? Will data automatically be saved as it is being collected? Or does the operator have to tell the system to save it? Is there any way to reduce the data? Should information from several scanning planes be put into a volume display? Should the digface characterization be done from up high and gradually do planes closer and closer to the surface?
- What is going to be done with all of the data that the characterization team collects? Data are raw right now. How do you relate what is seen in the data with what is really there? How do operators relate what they see on displays with what they see through the camera?

2.1.9.4 Interpret real-time results (HF)

2.1.9.5 Print hardcopy, if needed

2.1.10 Stop scan (stop manual mode or override automatic mode) (HF)

2.1.10.1 Planned

2.1.10.2 Abnormal

2.1.11 Process data if other than real-time data are needed

- This would probably be done by the characterization team.

2.1.12 Display processed data

- Who needs the data? How do they get it?

2.1.13 Convey and communicate data

- Industrial hygienists might be called in to do further sampling of air or soil. Excavation planners might need to order special excavation equipment (e.g., cutting torches) if an object is located that is too large or bulky to be handled with existing equipment or techniques. Health physicist might be called in to determine potential exposure (e.g., calculating dose rate) if someone must enter the containment building. And what will cutting torches do when used on large pieces of metal in the containment environment?
- Since this task has never been done before, it is unknown just how data will be interpreted or exactly what will be needed for interpretation. The details cannot be predicted.

2.1.13.1 Real time data (HF)

2.1.13.2 Processed data (HF)

2.1.13.3 Request something of characterization team (e.g., perform another operation) (HF)

2.1.13.4 Request by characterization team (e.g., ask crane operator to prepare for another scan) (HF)

2.1.14 Recharacterize digface

- The entire digface characterization task is a loop, gathering information that feeds back into the next pass of digface characterization sensors.

2.1.15 Archive data

- How will this be done? After every sweep? After the entire area is done? Will there be a difference in procedure between quick and detailed scans? What about file names? Where does the data go? How accessible is it? When a lot of data are being collected, what happens when the disk is filled? How often will this happen? Will this be done by the operator or automatically by the system? Will there be intermittent backups in addition to archives? Media to archive to?

2.1.16 Human errors:

2.1.16.1 The gantry crane operator can err by running the crane into the ground, damaging sensors and/or the manipulator arm. Sensors are expensive.

2.1.16.2 The characterization team could acquire bad data and pass it on as valid. The gamma and neutron sensors are fairly well understood, but the VOC sensor requires a knowledge of what is being searched for. The characterization team must know what is expected in order to tell if data is valid, invalid, or if equipment/sensors are not working properly.

2.1.16.3 Operator could fail to detect data that are there.

2.1.16.4 Potential problems with intricacies of data handling and display due to large amount of software involved. Inadequate training, inconsistent displays, etc. could contribute to operator error.

2.1.16.5 There could be errors and inadequacies in programming the software.

2.2 Shoring

- Vertical pieces of sheet steel will be put into zones in the pit to separate waste areas for retrieval. Sensors are needed to ensure that excavator and other tools do not "hit" shoring.
- Grouting is a type of shoring technique, but it has its own task description.
- Collision avoidance is needed to ensure that the excavator and other equipment do not bang into the shoring when maneuvering in the dig area.
- Need some type of fail safe collision avoidance so that if operators lose vision, the system freezes.
- Excavator uses a three-step procedure: dig, "stroke" to the conveyance, and dump.
- A contract has been let for a device to be attached to the excavator bucket that will cut down on the dust generated when digging and dumping. More than one end effector may be available for the excavator in the future.
- Will all shoring be installed perpendicular to the surface of the land?
- What is the weight of the support posts and sheets of steel? If they are too heavy for the manipulator arms and they must be handled by the hoist, how are they maneuvered and guided?

- Does the installation and use of shoring to support the sides of the access pit differ from that used to support digfaces during waste retrieval?
- What type of technology is used to position the piles in the ground?
- We need more detail about types of shoring.

2.2.1 Determine need for shoring (HF)

- What data/information are needed? Where are these available? Who makes this determination? How is it communicated to those who need to know?

2.2.1.1 Determine need for perimeter shoring (SME)
2.2.1.2 Determine need for access pit shoring (SME)
2.2.1.3 Determine need for waste seam shoring (SME)
2.2.1.4 Determine need for hot spot shoring (SME)

2.2.2 Know characteristics of available shoring methods (HF)

- What kind of information are needed. Where does a person learn it? Who needs to know it?

2.2.2.1 Metal (SME)
2.2.2.2 Hard plastic (SME)
2.2.2.3 Grouting (SME)
2.2.2.4 Cryogenic (SME)

2.2.3 Determine area for shoring (HF)

- What data/information are needed? Where are these available? Who makes this determination? How is it communicated to those who need to know?

2.2.3.1 Determine perimeter of area to be shored up (HF)
2.2.3.2 Determine depth to which shoring is needed (HF)
2.2.3.3 Match current conditions to shoring methods (HF)

2.2.4 Choose method for shoring (HF)
2.2.5 Plan shoring construction (HF) (e.g., where supporting posts will be installed, where material will be injected into the ground, etc.)
2.2.6 Determine materials needed to employ chosen shoring method (HF)
2.2.7 Obtain materials needed for chosen shoring method (HF)
2.2.8 Coordinate with other equipment (HF)
2.2.9 Move shoring materials to appropriate area (HF)

2.2.9.1 Use manual procedures (HF)
2.2.9.2 Employ conveyance (HF)
2.2.9.3 Employ other means (HF)
2.2.9.4 Use remote procedures (HF)

2.2.9.4.1 Employ conveyance (HF)
2.2.9.4.2 Employ manipulator (HF)
2.2.9.4.3 Employ hoist (HF)
2.2.9.4.4 Employ excavator (HF)

2.2.10 Install shoring materials (HF)

- How much of the shoring will be installed prior to erection of the containment building? How much will be installed within the containment building? What equipment will be used to install materials that are injected into the ground under high pressure?

- What are the steps needed to employ each method of shoring? What equipment will be needed? What information will be needed? Where will displays and controls be located? Who will do the actual installation? How will people know the installation has been successful?

2.2.10.1 Use metal (SME)
    2.2.10.1.1 Employ "in person" procedures (HF)
    2.2.10.1.2 Employ remote procedures (HF)
2.2.10.2 Spray hard plastic (SME)
    2.2.10.2.1 Employ "in person" procedures
    2.2.10.2.2 Employ remote procedures (HF)
2.2.10.3 Grout identified area (see grouting task)
    2.2.10.3.1 Employ "in person" procedures (HF)
    2.2.10.3.2 Employ remote procedures (HF)
2.2.10.4 Use cryogenics (SME)
    2.2.10.4.1 Install pipes
2.2.10.4.2 Freeze selected area

2.2.11 Determine adequate shoring of digface sides (HF)
- Who does this? How is it done? Who needs to know the results of this determination. What information is needed?
- May possibly use grouting/fixant on shoring materials after installation

2.2.12 Clean up shoring construction area (HF)
    2.2.12.1 Employ manual procedures (HF)
    2.2.12.2 Employ remote procedures (HF)

2.2.13 Clean up shoring construction tools (HF)
    2.2.13.1 Employ manual procedures (HF)
    2.2.13.2 Employ remote procedures (HF)

2.2.14 Normal shut down procedures

2.2.15 Abnormal shut down procedures

2.3 Grouting system (hot spot retrieval and contamination control)
- Who does it? How is it done? Information needs? Feedback needs?
- Grouting will apparently be done prior to the construction of the containment building.
- What piece of equipment handles the tools for injecting the grout and for injecting the expansion grout to break up the initial block of grout? In 1995 grouting will be done manually, and not from the HECS. Major modifications to equipment and/or procedure will be needed to operate this equipment remotely because of limitations on gantry crane arms. See gantry crane generic task for steps to attach a tool to the manipulator arms (e.g., move crane to tool storage area, position arms to attach particular tool, attach tool to arm, and verify).
- If grouting for hot spot removal is done before the construction of the containment building, how do the operators know where to do it? The location of the hot spots in 1995 will be known. Historical information and site characterization data will be important in a real world situation. One problem associated with the characterization used in association with hot spot retrieval is that a hot spot may be in one location, but there may be a path for the radiation or chemical vapors leading to detection at a location that is not immediately above the actual hot spot.

2.3.1 Determine need for grouting (HF)

2.3.1.1 Obtain and analyze historical data (HF)
2.3.1.2 Obtain and analyze site characterization data (HF)

2.3.2 Plan grouting activity (HF)
2.3.2.1 Determine area for grouting (HF)
2.3.2.2 Determine materials for grouting (HF)

2.3.3 Plan coordination with other pieces of equipment (HF)

2.3.4 Attach grouting tool to manipulator

2.3.5 Move crane with grouting tool to desired location (HF)
2.3.5.1 Move crane to desired location (HF)
2.3.5.2 Position tool for operation (HF)

2.3.6 Enable grouting tool (HF)

2.3.7 Drill injection holes (HF)

2.3.8 Inject/spray grout (HF)

2.3.9 Determine injection of grout in desired area is complete (HF)

2.3.10 Ensure grout solidification

2.3.11 Drill holes for expansion grout

2.3.12 Inject expansion grout

2.3.13 Verify breakup of grout

2.3.14 Determine removal method (HF)
2.3.14.1 Characterize current situation (HF)
2.3.14.2 Anticipate future situation (HF)
2.3.14.3 Know removal techniques available (HF)
2.3.14.4 Match appropriate removal technique with current/future situation (HF)
2.3.14.5 Communicate removal method to those who need to know (HF)

2.3.15 Plan removal

2.3.16 Communicate plan to those who need to know

2.3.17 Remove grout block to conveyance (see task analysis associated with chosen removal technology, e.g., vacuum, excavator)

2.4 Misting

- Contamination control unit includes hose reels, pumps, tanks, and controls for materials needed for contamination control (e.g., compressed air, water, fixative chemical(s), fixative foam). It generates information regarding tank levels, pump RPM, pump pressure, and the play-out of hoses.
- Contamination control activities are expected to occur 24 hours a day with misting associated with active work on the digface, and other activities (e.g., misting or spraying fixative on the floor beneath the excavator) occurring at other times.
- Misting will likely occur at the same time as digging or vacuuming.
- Hoses will be located in a "cable tray."
- Tanks will be located outside of the containment building. Tanks will hold 375 gallons. Anticipated rate of spraying will allow for approximately 150 minutes of spraying from a single tank of water. Changing tanks is estimated to take about 30 minutes.
- Mist may need to be applied to digface and to dirt floor under excavator and perhaps around conveyance. Dust free dumping process should minimize airborne dust associated with that function.

- Misting can control dust, but how do you keep from generating mud at times on hoses/equipment and/or in digging area?

2.4.1 Determine need for misting (HF)
2.4.2 Coordinate need with other equipment (HF)
2.4.3 Determine area for misting (HF)
2.4.4 Attach misting tool (HF)
  2.4.4.1 Move gantry crane to tool storage area (HF/SME)
  2.4.4.2 Position manipulator arm for attaching misting tool (HF/SME)
  2.4.4.3 Connect misting tool to manipulator arm (SME)
  2.4.4.4 Determine that tool is operational (SME)
    2.4.4.4.1 Ensure power available (SME)
    2.4.4.4.2 Ensure hoses and nozzles clear (SME)
    2.4.4.4.3 Ensure water and compressed air available (SME)
2.4.5 Move misting tool to appropriate area (HF)
  2.4.5.1 Move gantry crane to working area (HF/SME)
  2.4.5.2 Position tool for misting (HF/SME)
2.4.6 Apply mist (HF)
  2.4.6.1 Initiate spray (SME)
  2.4.6.2 Monitor performance of mist tool and availability of water and compressed air (HF)
  2.4.6.3 Coordinate misting equipment with other equipment (e.g., digging equipment, conveyance) (HF)
  2.4.6.4 Monitor effects on dust and soil (HF)
  2.4.6.5 Ensure that mist does not obscure camera vision (HF)
  2.4.6.6 Ensure that mist tool does not conflict with other equipment (HF)
  2.4.6.7 Turn off spray (HF)
2.4.7 Prepare for maintenance/storage (HF)
  2.4.7.1 Clear hoses and nozzles (HF)
  2.4.7.2 Clean hoses and nozzles; other equipment (HF)
2.4.8 Perform maintenance (HF)
2.4.9 Move to storage area (HF)
2.4.10 Store misting equipment (HF)

2.5 Fixant (hot spot retrieval, full-scale retrieval, contamination control, and overburden removal)

- A fixant can be applied to help stabilize soil to minimize dust generation. Fixants under consideration include chemicals and 3M foam.

2.5.1 Determine need to apply fixant (HF)
  - Who makes this determination? How is it communicated to those who need to know? Who actually needs to know?

  2.5.1.1 Characterize current situation
    2.5.1.1.1 Obtain and analyze historical data (HF)
    2.5.1.1.2 Obtain and analyze site characterization data (HF)
  2.5.1.2 Anticipate future situation) (HF)
2.5.2 Determine area for fixant application (HF)
2.5.3 Know different types of fixant available (HF)
2.5.4 Match appropriate type of fixant with current/future situation
  2.5.4.1 Choose chemical (HF)

2.5.4.2 Choose foam

2.5.5 Plan fixant activity (e.g., what, where, how, how much etc.) (HF)

2.5.6 Coordinate fixant activity with other equipment in the area

2.5.7 Attach proper tool to crane (see generic gantry crane task) (HF)

- Who does this? Controls, displays, verification?

2.5.7.1 Move crane to tool storage area (HF)

2.5.7.2 Position manipulator arm for attaching tool (HF)

2.5.7.3 Connect tool and associated power cords, hoses, nozzles, etc. to crane (HF)

2.5.7.4 Determine that tool is operational (e.g., power available, hoses/nozzles clear, materials available, etc.) (HF)

2.5.7.5 Move crane with tool to appropriate area (HF)

2.5.8 Apply fixant (HF)

2.5.8.1 Initiate flow (HF)

2.5.8.2 Monitor performance of tool and availability of materials (HF)

2.5.8.3 Monitor effects of fixant on soil (HF)

2.5.8.4 Ensure that tool does not conflict with other equipment (HF)

2.5.8.5 Ensure that fixant does not obscure camera vision (HF)

2.5.9 Terminate application of fixant (HF)

2.5.9.1 Use normal procedure (HF)

2.5.9.2 Use abnormal procedure (HF)

2.5.10 Prepare for maintenance/storage (HF)

2.5.10.1 Clear hoses and nozzles (HF)

2.5.10.2 Clean hoses and nozzles; other equipment (HF)

2.5.11. Perform maintenance (HF)

- Who, manual, remote, where, controls, displays, verification?

2.5.12 Move to storage area

2.5.13 Remove and store tool (HF) (see generic crane task)

2.6. SONSUB end effector system (Overburden removal)

- SONSUB end effector is to help contain dust during overburden removal.
- Cold test pit has waste located in five zones: (1) random boxes and drums, (2) random drums, (3) stacked boxes and drums, (4) stacked drums, and (5) large objects.
- Original plan for FY-95 demo was for remote, full-scale retrieval. Proposed plan for FY-95 (at the time of this writing) involves use of six different procedures to remove waste from the five different zones in the cold test pit: (1) manual excavation of hot spots using excavator for hot spot removal to determine baseline data, (2) remote excavation of hot spots using remote operation of excavator for hot spot removal, (3) excavation using vacuum technology, (4) excavation off the gantry crane, (5) use grouting technology to stabilize hot spots and then remove them, (6) operate excavator remotely from belowgrade to do full excavation with no contamination control. The goal is to gather data about time, dust, and difficulties associated with each of the six scenarios.
- FY-93 demonstration used end effector to plane off 3, 4, or 6 in. of soil. End effector was deployed off a caterpillar. Required all available power to pull the device through the soil. Goal for FY-95 is to modify the SONSUB end effector so that it has its own power source. It cannot be deployed off the gantry crane.

- SONSUB end effector is to be used only to remove clean soil from the over burden.
- Basic scenario is to scan a path, remove 6 in. of overburden; scan a new path, remove 6 in. of overburden, and continue in this fashion until multiple hazardous situations (radiation or volatile organic compounds) are encountered.
- Each strip of soil that is removed is approximately 2 ft wide.
- One strip of soil 2 ft × 50 ft × 6 in. would yield approximately 2 yd^3 of soil. Therefore, the end effector would probably have to dump its load of soil before completion of a single path is completely dug up.

2.6.1 Determine need to remove 6-in. layer of overburden
2.6.2 Determine area for overburden removal
2.6.3 Decide to use SONSUB for overburden removal
2.6.4 Attach SONSUB to excavator
2.6.5 Determine SONSUB is operational
    2.6.5.1 Determine power is available to operate SONSUB
2.6.6 Determine SONSUB path
    2.6.6.1 Identify possible path
    2.6.6.2 Perform digface characterization of possible path
    2.6.6.3 Select type of path
        2.6.6.3.1 Choose continuous path when there are not obstacles
        2.6.6.3.2 Choose interrupted path when there are isolated obstacles
2.6.7 Determine mode of operation on chosen path
    2.6.7.1 Use automated operation along chosen path when no hazards (radiation or volatile organic compounds) have been detected
    2.6.7.2 Use teleoperation along chosen path when isolated hazards (radiation or volatile organic compounds) have been detected
2.6.8 Move SONSUB to chosen path start point
2.6.9 Collect overburden using SONSUB
    2.6.9.1 Position digging surface of SONSUB on site surface
    2.6.9.2 Issue command to start SONSUB moving on chosen path
        2.6.9.2.1 Issue command for automatic, preprogrammed operation
        2.6.9.2.2 Issue command for remote, teleoperation
    2.6.9.3 Monitor progress of SONSUB along path
        2.6.9.3.1 Track location on path
        2.6.9.3.2 Verify SONSUB is level
    2.6.9.4 Stop SONSUB
    2.6.9.5 Tilt SONSUB container to contain material
2.6.10 Transport SONSUB to conveyance
    2.6.10.1 Hoist SONSUB vertically from digface
    2.6.10.2 Move SONSUB horizontally to conveyance
    2.6.10.3 Position SONSUB with respect to conveyance to deposit load
2.6.11 Deposit overburden into conveyance
2.6.12 Determine overburden removal is complete
2.6.13 Determine need for SONSUB is complete
2.6.14 Remove SONSUB from excavator

2.7 Vacuum

- The vacuum is a large piece of equipment which weighing about 4,000 lb, which will be moved by the hoist (other information sources say this is not possible). It is estimated that selective waste retrieval using vacuuming techniques will be underway during about 25 to 30% of the time.

2.7.1 Determine need for retrieval or removal (HF)

- Who makes this determination? To whom does this determination need to be communicated? What data/information are needed to make this decision? Where are these data/information available? When does this determination need to be made? How much time is needed to make this determination?

2.7.2 Determine area for retrieval or removal (HF)

- Who makes this determination? To whom does this determination need to be communicated? What data/information are needed to make this decision? Where are these data/information available? When does this determination need to be made? How much time is needed to make this determination?

2.7.3 Attach vacuum to gantry crane (HF)

2.7.3.1 Move gantry crane to "front door" of tool storage area. (SME)

2.7.3.2 Move gantry crane to position to pick up vacuum unit. (SME)

2.7.3.3 Use manipulator arm to position hook (SME)

- Is hook located on vacuum unit or on hoist? What controls and displays are associated with this task?

2.7.3.4 Pick up vacuum unit with hoist (SME)

- What controls are used for this task? What display information is associated with this task? Is this task likely to be automated or teleoperated? Will hoist and manipulator arm be operated by different individuals? What communication and coordination is needed? How are collisions avoided?

2.7.3.5 Use manipulator arm to attach power cord to vacuum?

- Does the vacuum also have hoses (or some sort of attachments) that are used to direct the suctioning power of the vacuum to remove dirt in a particular area? How are these hoses manipulated? Where does the dirt that is "vacuumed" go (bag, bin, box, conveyance)?

2.7.4 Move vacuum system to appropriate area (HF)

- Does the big vacuum unit have to be placed in a particular way when it is in operation (e.g., level, a certain distance from the digface, a certain distance from other equipment)?
- Who makes the decision regarding the mode of operation? What steps are associated with teleoperation? What steps are associated with automatic operation (simply issuing a command)?

2.7.4.1. Teleoperation (HF)

2.7.4.2. Automatic operation

2.7.5 Enable vacuum system (HF)

- What steps are associated with this task. What controls and displays are associated with each step in this task?

2.7.6 Remove/retrieve waste/dirt using vacuum system

- What controls and displays are needed to operate the vacuum? Who in the HECS needs this information?

- What are the steps associated with each mode of operation? What are the controls and displays associated with each mode of operation? What are the information needs associated with each mode of operation?

2.7.6.1 Teleoperation (SME)

2.7.6.2 Automatic operation (SME)

2.7.7 Monitor process of waste collection (HF)

- What information is generated during this process. Who has access to this information? What controls and displays are used in this process?

2.7.7.1 Monitor progress of vacuuming (HF)

2.7.7.2 Monitor health of equipment (HF)

2.7.7.3 Monitor location of other equipment to avoid collisions (SME)

2.7.7.4 Monitor interactions with other equipment (e.g., conveyance, misting) (HF)

2.7.8 Determine current vacuuming operation is complete (HF)

- Who makes this decision? To whom is this decision communicated? How is it communicated? What information is needed to make this decision? How is the information displayed? Where is it displayed?

2.7.9 Remove vacuum system from crane

2.7.9.1 Move gantry crane to "front door" of tool storage area. (SME)

2.7.9.2 Move gantry crane to position to remove vacuum unit. (SME)

- What are the remaining steps in this task? (They would seem likely to involve placing vacuum in proper location, detaching vacuum from hoist, detaching umbilical cords, and storing them properly.) What are the information needs of this task? What controls and displays are associated with this task? Who needs this information? How is the performance of this task coordinated with any other activities that may be occurring?

2.8 General Contamination Control (generalized contamination control task generated by HF)

- It is anticipated that some type of contamination control may occur 24 hours per day. Misting to control airborne dust particles will occur during digging operations. Use of soil fixants (e.g., 3M foam) and various types of dust suppressing chemicals is likely to occur at other times (e.g., suppressing the dust along the path used by the conveyance, and the floor of the pit under the excavator).
- Contamination control will be employed in a number of different areas: digface, floor of pit under excavator, path used by conveyance, packaging area.
- There has been no effort devoted to considering ventilation in the containment building and the possible role of ventilation in contamination control.

2.8.1 Determine need for contamination control

2.8.1.1 Characterize current situation

2.8.1.1.1 Obtain and analyze dust monitoring data

2.8.1.1.2 Obtain and analyze other sources of data

2.8.1.2 Anticipate future situation

2.8.2 Know different types of contamination control (CC) available

2.8.3 Match appropriate type of CC with current/future situation

2.8.4 Match appropriate CC technique with current/future situation

2.8.4.1 Choose misting (see task 1.4.1: determine need for misting)

2.8.4.2 Choose dust suppressing chemical

2.8.4.3 Choose soil fixant (see task 1.5)

2.8.4.4 Choose dust-free dumping end effector for excavator (see task 3.2)

2.8.5 Coordinate CC equipment with other equipment in the area

2.8.6 Monitor results of use of chosen CC technique

2.8.7 Monitor CC equipment health (RPM, pressure, etc.)

2.8.8 Ensure CC materials are available (e.g., tanks of water, compressed air, chemicals)

2.8.9 Perform preventive/routine maintenance

2.9 Tools (digface sampling)

2.9.1 Determine need for digface sampling

2.9.2 Determine area for digface sampling

2.9.3 Attach digface sampling tool to manipulators

2.9.4 Move digface sampling tool to appropriate area

2.9.5 Enable digface sampling tool

2.9.6 Return the sample to collection area

2.9.7 Remove sample from the digface sampling tool

2.9.8 Remove digface sampling tool

2.10 Tools

- The following is a best guess but more information is needed. (Hot spot retrieval, full-scale retrieval, and overburden removal)

2.10.1 Determine need for retrieval or removal

2.10.2 Determine area for retrieval or removal

2.10.3 Determine specific tool to be used

2.10.4 Move retrieval or removal tool to appropriate area

2.10.5 Enable retrieval or removal tool

2.10.6 Remove overburden or retrieve waste using retrieval or removal tool

2.10.7 Ensure integrity/monitor the waste collection device

2.10.8 Remove collection device

2.10.9 Remove retrieval or removal tool

2.11 Interferometer (digface and site characterization, hot spot retrieval, full-scale retrieval, and overburden removal)

- How will the interferometer data be integrated with the rest of the characterization data? How will it be processed so as to be useful for operators?

2.11.1 Plan/define scan area (geometry, equipment, etc.)

2.11.2 Locate interferometer to cover planned scan area

2.11.3 Enable interferometer

2.11.5 Collect data

2.11.6 Process data

2.11.7 Archive processed data

2.11.8 Monitor processed data

2.11.9 Display processed data to characterization team

2.12 Ground Penetrating Radar (GPR) (digface and site characterization, hot spot retrieval, full-scale retrieval, and overburden removal)

- How will the GPR data be integrated with the rest of the characterization data? How will it be processed so as to be useful for operators?

2.12.1 Plan/define scan (geometry, equipment, etc.)

2.12.2 Transmit/give plan to digface/gantry crane operator

2.12.3 Enable GPR

- 2.12.4 Teach plan to gantry crane/manipulator
- 2.12.5 Initialize/scan and collect data
- 2.12.6 Archive data during scan
- 2.12.7 Process data
- 2.12.8 Display processed data to characterization team

2.13 Sizing (generalized sizing task generated largely by HF)

- It is anticipated that the shears will serve as the primary technology for sizing and that cryogenic cutting will be used to supplement the capabilities of the shears.
- It is anticipated that there may be a "sizing booth" where the cryogenic cutting equipment is operated.
- Will the crane operator have to excavate around an object prior to moving, or sizing it?
- Will all sizing occur at a specific location?

- 2.13.1 Determine need to size a particular object (SME)
  - 2.13.1.1 Characterize current situation (will require estimating size of object with respect to size of conveyance)
    - Who does this task? What information is needed to perform this task? Where is this information available?
  - 2.13.1.2 Anticipate future situation
- 2.13.2 Know types of sizing available
- 2.13.3 Match appropriate sizing technology with current/future situation
  - 2.13.3.1 Choose to use the shears
  - 2.13.3.2 Choose to use cryogenic cutting (see task 2.14)
  - 2.13.3.3 Choose to set large object aside and to continue with retrieval activities
    - What piece of equipment will be used to set large object aside?
- 2.13.4 Plan a course of action to size object using chosen approach to sizing
  - 2.13.4.1 Determine necessary "cutting" operations
  - 2.13.4.2 Determine placement of object relative to chosen cutting technology
- 2.13.5 Coordinate need to use sizing equipment with activities of other equipment in the area
- 2.13.6 Attach sizing tool (SME)
  - How much do the shears and the cryogenic cutting equipment weigh? What are the hoses, power sources, etc. that are associated with cryogenic cutting.
- 2.13.7 Move sizing tool to appropriate area (SME)
- 2.13.8 Grasp object to be sized and place object for sizing (SME)
  - What piece of equipment does this . . . hoist? crane arm? excavator? Will object need to be moved from where it is discovered to be sized? Will object need to be in a specific position relative to shears to be sized?
- 2.13.9 Enable sizing tool (SME)
  - What steps are associated with this task?
- 2.13.10 Size object to fit in 4 × 4 × 8 box (SME)
  - What kinds of forces are necessary to operate the shears and cryogenic cutting tools? what kind of manipulation ability will be needed to operate the shears and cryogenic cutting equipment?
- 2.13.11 Monitor progress of sizing activity

2.13.12 Monitor sizing equipment system health
2.13.12 Ensure material needed by sizing equipment (e.g., liquid nitrogen) is available
2.13.13 Disable sizing tool (SME)
2.13.14 Move sizing tool back to tool storage area (SME)
2.13.15 Disconnect sizing tool from gantry crane (SME)
2.13.16 Remove sized pieces (SME)
2.13.17 Perform preventive/routine maintenance
- What piece of equipment does this task hoist? crane arm? excavator? conveyance? How are they coordinated?

2.14 Cryogenic cutting
- Cryogenic cutting will be used when objects are too large to be sized by the shears.
- The speed at which cryogenic cutting can be accomplished is a question at this time. It may be that this technology will be used to augment the capabilities of the shears by cutting a hole in a large object (e.g., puncturing a sealed container) to enable the shears to "nibble" the object into manageable pieces. At this point in time, the shears are a far more efficient cutting tool.
- Cryogenic cutting tool may be permanently attached to the Z-mast of the gantry crane with positioning in terms of x, y, z coordinates (head with 5 degrees of freedom would be adequate). In this scenario, it may be necessary to move the object in order to orient it properly for cutting, rather than angling the head of the cutting tool.
- What equipment would be used to manipulate the large object?
- Alternatively, there may be a sizing booth (approximately 10 × 15 × 15 ft) where cryogenic cutting occurs. This scenario would eliminate the need to transfer liquid nitrogen long distances. The sizing booth could be somewhat mobile so that it would be moved as the digface moves. (The sizing booth is the most likely scenario.)
- When operating the cryogenic cutting tool, liquid nitrogen (at 60,000 psi) is used like a water jet. Actual pressure through nozzle is less because much of the nitrogen has become a gas rather than a liquid.

2.14.1 Determine need to use cryogenic cutting to size a particular object (SME)
2.14.2 Determine placement of object relative to cutting equipment (HF)
- Who does this? What information is needed?

2.14.3 Move appropriate object/equipment
2.14.3.1 Move object to be sized (SME)
- This task would probably require the hoist with assistance from the manipulator arms to position slings. (SME)
- The excavator might also be used to move large objects.

2.14.3.2 Move gantry crane with cutting tool attached to Z-mast (SME)
2.14.3.3 Verify object and equipment are located properly for cutting operation to proceed (HF)
2.14.4 Enable cryogenic cutting tool using appropriate computer software (SME)
- What steps are needed to perform this task?
- System will probably use open-loop control
- Current software is "user intensive"

2.14.5 Program cryogenic tool to make desired point-to-point cut(s) (SME)

- It is likely that the location of the cut will be indicated by specifying two or three points and that a series of short cuts involving frequent interaction with the operator will be used.
- There is a possibility that a laser system will be used to target the location of the desired cut.

2.14.6 Position cryogenic tool to begin cutting (SME)
- Television cameras may be used to aid in positioning the cryogenic cutting tool

2.14.7 Perform desired cut(s) (SME)
- 2.14.7.1 Issue command to begin cutting (HF)
- 2.14.7.2 Confirm command to begin cutting has been received (HF)
- 2.14.7.3 Monitor progress of cut (HF)
- 2.14.7.4 Verify cut is completed (HF)

2.14.8 Disable cutting tool (SME)
- What steps would be involved with this task?

2.14.9 Replace cutting tool (SME)
- Steps involved in this task? Are they different depending on whether the tool is mounted on the gantry crane Z-mast, or used in a dedicated sizing area?

2.14.10 Remove sized pieces (SME)
- What steps are involved in this task? What piece of equipment would be involved?

Other notes:
- Equipment associated with this tool includes a 200 to 250 hp hydraulic unit that will be located outside the contamination control building. Therefore, maintenance should be relatively easy.
- Maintenance needs include checking torque of fittings, greasing bearings of motor, and swapping nozzles for maintenance. At this time, there is no way to determine if a new nozzle is good. Maintenance of nozzle may be a glove box operation.
- Hoses for liquid nitrogen need to be short. When they are short, it is relatively easy to tell if there is a leak, or if the hose loses a seal, and it is relatively easy to fix. Currently, about 2,000 hours between failures.
- Intensifier (increases psi to 60,000) needs to be as close as possible to sizing operation because the length of the hose between the intensifier and the nozzle needs to be as short as possible.
- Venting of nitrogen gas generated during the cutting operation is needed.
- Abnormal operations would occur if a high pressure tube ruptures. There should be an emergency stop. However, any shut down requires the ability to vent gas pressure.
- Abnormal operations may also occur when the flow of nitrogen stops because of freezing in the tubing. A transducer could alert system operator that this has occurred. An emergency stop button should be available.
- There is some work being done to develop a covariant-based control system for the jet. It would be rather like system health monitoring, except that its function would be to anticipate problems. It would examine the performance of the nozzle and alert the operator when needed. At this time, there are no flow monitoring devices that could be used to perform this function.

- If the cryogenic cutting tool is deployed off the gantry crane, it would probably be operated by the gantry crane operator. If it is deployed in a separate sizing area, there would probably be a dedicated sizing operator although this person could be a gantry crane operator.
- How would the cutting tool be deployed in a dedicated sizing area?
- A 6,000–12,000 gal tank of liquid nitrogen will needed in conjunction with this tool.
- At the present time, the cryogenic cutting tool cuts at a rate of about 1 in. every 30 minutes, and it cannot cut through anything that is very thick.
- Shut down procedures should be automated, and there needs to be a fail safe mode.
- Dirt is not an impedance to the cutting operation of this system.

2.15 Hoist {The following is a best guess but need more information is needed.} (Hot spot retrieval, full-scale retrieval, and overburden removal)

2.15.1 Determine need for retrieval or deployment of heavy items that exceed capacity of the manipulators

2.15.2 Move hoist to appropriate area

2.15.3 Connect/rig the hoist to the heavy item

- How will this be done? What other equipment will be involved?

2.15.4 Enable hoist

2.15.5 Retrieve or deploy heavy item

2.15.6 Place the heavy item in the waste collection device or on the conveyor or possibly size

2.15.7 Disconnect and move the hoist

3. Excavator

3.1 Full-scale retrieval

3.1.1 Determine need for retrieval (HF)

3.1.1.1 Characterize current situation (HF)

3.1.1.2 Anticipate future situation (e.g., next function that must be performed)

- Who does this? What information is needed?

3.1.2 Determine area for retrieval (HF)

- Who does this? What information is needed?

3.1.3 Plan retrieval of material (HF)

3.1.3.1 Use innovative end effector and scoop dirt (HF)

3.1.3.2 Use bucket and Balderson thumb to pick up barrel or other large object (HF)

3.1.3.3 Coordinate plans with activities of other pieces of equipment in the area (HF)

- How close does the mister have to be to the excavator bucket to be effective? How far does the mister have to be from the excavator bucket to ensure that there is no collision? Assuming the excavator is not an automated operation, how do you avoid the manipulator arms? It would seem as if the excavator arm could "wipe out" a manipulator arm really easily.

3.1.4 Enable excavator (HF)

- What steps are associated with this task? (HF)

- This analysis assumes that each time the excavator "dumps" a load in the conveyance, a new end effector is attached to the excavator so that it is ready to be deployed to dig where desired. (HF)

3.1.5 Move excavator to appropriate area (HF)

3.1.6 Retrieve load of waste (may involve misting and sizing) (HF)

3.1.6.1 Using innovative end effector (HF)

3.1.6.1.1 Position end effector to get dirt (SME)

3.1.6.1.2 Scoop dirt/waste (SME)

3.1.6.1.2.1 Move bucket into digface (SME)

3.1.6.1.2.2 Curl bucket as you cut into digface (SME)

3.1.6.1.2.3 Lift bucket away from digface (SME)

3.1.6.1.2.4 Monitor video and other types of feedback while operating bucket (SME)

- If the misting process results in mud, does this fact affect the digging process in any way?

3.1.6.2 Using bucket and Balderson thumb (HF)

3.1.7 Move load from digface area (HF)

3.1.7.1 Place load in conveyance (HF)

- The conveyance requires targets for positioning.

3.1.7.1.1 Place end effector in conveyance (HF)

3.1.7.1.1.1 Position end effector with respect to conveyance (HF)

3.1.7.1.1.2 Release end effector (HF)

3.1.7.1.1.3 Attach new end effector (HF)

- Would this attachment take place in conjunction with the conveyance, or at a separation location?

3.1.7.1.2 Place other type of load in conveyance (HF)

3.1.7.2 Place load aside (HF)

3.1.8 Ensure integrity/monitor the waste collection device (HF)

3.1.9 Remove excavator (HF)

Notes

1. There has been some remote operation of excavators in a line of sight mode of operation.
2. It is anticipated that a large number of cameras (c. 8-10) will be deployed in conjunction with the activities of the excavator. Other types of data associated with the use of the excavator include output from sensors, auditory data from engine noises, and data related to system health.
3. It is anticipated that eventually routine maintenance will be handled remotely. The air lock should be big enough to handle a semi-truck so that large equipment could be maintained inside the airlock, or even towed outside.
4. Removal of grout during hot spot retrieval would probably use a clam shell off the gantry crane; removal of grout during full-scale retrieval could probably be accomplished by the excavator.

Questions

1. The excavator is intended for full-scale retrieval. Are any tools other than the vacuum available for removing dirt during hot spot removal.
2. How stable is the surface of the pit in terms of heavy equipment driving across it and being located on it during excavation operations?
3. What are the effects of uneven rock surfaces at the bottom of the pit when you get near the bottom in full-scale retrieval?

Possibilities for errors/abnormal events

1. Operator may not dig deeply enough to retrieve a full-load of dirt. Operator may dig too deeply so that the bucket gets stuck in the dirt. Operator may undercurl, or overcurl, the bucket and drop some dirt/waste in the process.
2. Hydraulic leaks. These fluids can catch fire; they can also mix with waste in the environment.
3. An excavator could tip. At worst you could lose an excavator. At best you would lose time and money and would probably create more mixed waste.

General information about the last demonstration

1. Heavy shears were operated off a second excavator during the last demo, not off the same excavator as was used for digging.
2. The end effector used in the last demonstration is different from the one that will be used in the 1995 demonstration.

General information about the 1995 demonstration

1. No large shears will be deployed during the hot spot retrieval, although small "nuisance shears" may be deployed off of the gantry crane.
2. The innovative end effector will not be used in 1995 because that demonstration will involve hot spot retrieval, not full-scale retrieval. The innovative end effector is intended to be used for full-scale retrieval. The time needed to change end effectors is not known at this time, if a scenario included both hot spot and full retrieval.
3. One of the purposes of the 1995 demo will be to compare the use of the gantry crane and the excavator in hot spot retrieval.
4. Soil buster
    - Is the soil buster used off the manipulator arms or off the hoist?
    - Who is designing the tool storage area? What tools should be included? In what sequence should tools be stored? How will needed attachments (e.g., power cords, hoses, nozzles etc.) be stored and accessed by crane operator?
    - What start-up procedure is needed to enable the soil buster?
    - How do you interface with the soil buster? Is there more involved than simply making a positive connection with some sort of "t-handle?"
    - Can the gantry crane manipulator arms and hoist be used at the same time? Do the same personnel that operate the manipulator arms operate the hoist?
    - How do you control the soil buster? Are there controls for things like amount of power? Rate of revolution?

- Does the soil buster loosen soil from a stationary position or is it moved in some way as it is loosening soil?
- What information is displayed when soil buster is in operation? To whom is this information displayed? How is this information used?
- The soil buster is a tool that is operated off the gantry crane to break up soil so that it can be picked up by the vacuum. It is sort of like a rototiller.
- This task analysis assumes that a strategic/supervisory decision has been made to use the soil buster and that the crane is in its "home" location(see tasks analysis of general use of gantry crane)
- Prior to beginning the operation of attaching the soil buster to the gantry crane, decisions need to be made to use the soil buster, and these decisions need to be communicated to the appropriate crane operator. Plans also need to be made to ensure collision avoidance and to interact with other pieces of equipment (probably the vacuum, conveyance, and some type of contamination control such as misting). These plans also need to be communicated to the appropriate crane operator.

4.1 Move gantry crane to "front door" of tool storage area (SME)
  - 4.1.1 Issue command (HF)
  - 4.1.2 Confirm command has been received (HF)
  - 4.1.3 Monitor progress of crane (HF)
  - 4.1.4 Monitor control console information to determine crane has reached desired destination. (HF)
  - 4.1.5 Verify crane has reached desired destination using feedback from remote vision (HF)

4.2 Position crane manipulator arms/hoist within tool storage area to attach soil buster (SME)
  - 4.2.1 Issue command (HF)
  - 4.2.2 Confirm command has been received (HF)
  - 4.2.3 Monitor progress of crane (HF)
  - 4.2.4 Monitor control console information to determine crane has reached desired destination. (HF)
  - 4.2.5 Verify crane has reached desired destination using feedback from remote vision (HF)

4.3 Interface crane with soil buster (HF)
  - 4.3.1 Issue command (HF)
  - 4.3.2 Confirm command has been received (HF)
  - 4.3.3 Monitor progress of crane (HF)
  - 4.3.4 Monitor control console information to determine crane has reached desired destination. (HF)
  - 4.3.5 Verify crane has reached completed interface with soil buster using feedback from remote vision (HF)

4.4 Perform status check with soil buster (HF)
  - 4.4.1 Issue command (HF)
  - 4.4.2 Confirm command has been received (HF)
  - 4.4.3 Monitor status of soil buster (HF)
  - 4.4.4 Monitor control console information to determine status check has been completed. (HF)

4.5 Move crane with soil buster to desired location (SME)
  - 4.5.1 Issue command (HF)

4.5.2 Confirm command has been received (HF)

4.5.3 Monitor location of crane with soil buster to avoid collision with other equipment in the area. (HF)

4.5.4 Monitor control console information to determine crane has reached desired location (HF)

4.5.5 Verify crane has reached desired location using feedback from remote vision (HF)

4.6 Position soil buster to begin loosening dirt (HF)

4.7 Enable soil buster to loosen dirt (HF)

4.8 Loosen dirt (HF)

4.9 Guide soil buster

- How do you guide the soil buster when it is loosening soil? Do you program a path? Control it manually using some interface (e.g., joystick) in conjunction with remote vision?

4.10 Control soil buster

4.11 Coordinate with other equipment to remove loosened dirt (HF)

4.12 Determine that all soil that needs to be loosened in planned area has been loosened successfully (HF)

5. Conveyance System (removal of waste)

5.1 Coordinate with characterization team

5.2 Ensure clean/empty end effector bucket is on conveyance

5.3 Send conveyance to the digface

5.3.1 Start conveyance motor

5.3.2 Adjust camera as needed

5.3.3 Begin driving the conveyance toward the digface

5.3.4 Monitor conveyance for proper function

5.3.5 Position the conveyance in reception area

5.3.5.1 Locate the appropriate positioning target

- How will this be done? From how far away?

5.3.5.2 Align the conveyance with the target

5.3.5.3 Drive the conveyance to the proper position

5.3.5.4 Stop the conveyance

5.3.5.5 Verify that the conveyance is in the proper position

- How will this be done?

5.4 Pick up material

5.4.1 Open the conveyance box

5.4.2 Verify that the conveyance box is open

5.4.3 Notify other equipment operators that conveyance is ready to receive

5.4.4 Receive notice from other operators that placement of material in the box is complete and that their equipment is clear

5.4.5 Close the conveyance box

5.4.6 Verify that the conveyance box is closed

5.5 Send conveyance back to emptying area

5.5.1 Reverse camera view and driving direction

5.5.2 Begin driving the conveyance away from the digface

5.5.3 Monitor conveyance for proper function

5.5.4 Position the conveyance in emptying area

5.5.4.1 Locate the appropriate positioning target
5.5.4.2 Align the conveyance with the target
5.5.4.3 Drive the conveyance to the proper position
5.5.4.4 Stop the conveyance
5.5.4.5 Verify that the conveyance is in the proper position

5.6 Empty the conveyance
5.6.1 Put the conveyance in proper mode for unloading
5.6.2 Unload conveyance
5.6.3 Verify that conveyance is unloaded

5.7 Maintain the conveyance

5.8 Use conveyance for maintenance
5.8.1 Coordinate with mechanic on remote maintenance needs
5.8.2 Ensure appropriate maintenance materials are on conveyance
5.8.3 Send conveyance to the maintenance area (similar to 5.3)
5.8.4 Off-load and load maintenance materials as necessary (similar to 5.4)
5.8.5 Send conveyance back to emptying area (similar to 5.5)
5.8.6 Off-load any material loaded during maintenance functions

6. Dust sampling system

- Technician could need up to 1 hour per day to check system.
- Determining system status could be automated. (SME)
- Actual sampling unit will be mounted as a stationary fixture (probably suspended) near the building exit probably out of the way of other equipment. (SME)
- Trend information might be useful in determining when one is approaching a hot spot.
- There could be many controls involved in operating this piece of equipment.
- In some cases a decision might be made to override this system.
- What is displayed? Where are the displays located? How is it displayed?
- Should data generation/display be passive or active?
- Who receives any alarms? The supervisor?
- What is the background and training of the person(s) who will use the data? Will they need to be very knowledgeable about radiation?
- Who makes any shutdown decision? The supervisor?
- Who has the "button" to shut down operations? Who has the data on which to make such a decision? The supervisor?
- What does the operator look for in the data? Slow trends, spikes, or ramps up?
- How fast will a person have to make a decision regarding this system?
- Who monitors the data? A human? or a computer that then alerts a human?
- Who generates any alarms? A computer? or a human?
- What kinds of controls will be used? will it navigate through windows? Will commands be entered through a keyboard?
- If digging procedure is changed on the basis of trend information (e.g., pace is slowed, more misting is used), how long will it take to be reflected in data?
- How will changes in digging procedure impact on data (e.g., if you change procedure in some way, will it impact on your ability to interpret your data and trend information)?
- If a decision is made to override/ignore an alarm from the system, what are the consequences?
- What types of controls will be used to operate this system?
- Is there a warm-up and/or cool-down period needed for the lasers?

- Where do the data go? Who passes the data to whom?
- System will draw air through chambers containing lasers that use laser light scattering and laser spectroscopy to analyze ambient dust (size, concentration, composition) in the containment building. Data will be generated in real time and displays will most likely be updated every 30 to 60 seconds.
- System will be mounted near exit of building and will need daily calibration. Actual dust sampling unit will be a small box (maybe 1 ft^3), which is connected by fiber optic cables to additional equipment outside of the building. Data will probably be used by the supervisor/operator and by those responsible for health physics and industrial hygiene. Conventional continuous air monitoring (CAM) and other types of chemical monitoring will be used in addition to this system.
- Errors associated with the system could involve contamination and/or breakage of the window associated with the lasers. The fiberoptic cable could be damaged, and there could be "interference" in the data. In some cases errors would result in data which are off the scale. Regular maintenance may be required for windows, fiberoptics cables, and flash mechanisms needed for the lasers.

6.1 Start up (HF)
    6.1.1 Decide to enable system (HF)
    6.1.2 Enable system (turn it on) (HF)
    6.1.3 Calibrate system (SME)
6.2 Operate (HF)
    6.2.1 Generate data (SME)
    6.2.2 Display data (SME)
        6.2.2.1 Current data (updated every 30 to 60 seconds) (SME)
        6.2.2.2 Size and concentration of dust particles (SME)
        6.2.2.3 Composition of dust particles (ppm) (SME)
            6.2.2.3.1 Transuranics (SME)
            6.2.2.3.2 Other metals (SME)
    6.2.3 Trend data (SME)
        6.2.3.1 Size and concentration of dust particles (SME)
        6.2.3.2 Composition of dust particles (SME)
            6.2.3.2.1 Transuranics (SME)
            6.2.3.2.2 Other metals (SME)
6.3 Monitor displayed data (HF)
    6.3.1 Current data (HF)
        6.3.1.1 Size and concentration of dust particles (HF)
        6.3.1.2 Composition of dust particles (ppm) (HF)
            6.3.1.2.1 Transuranics (HF)
            6.3.1.2.2 Other metals (HF)
    6.3.2 Trend data (HF)
        6.3.2.1 Size and concentration of dust particles (HF)
        6.3.2.2 Composition of dust particles (ppm) (HF)
            6.3.2.2.1 Transuranics (HF)
            6.3.2.2.2 Other metals (HF)

6.4 Generate alarm (SME)
  6.4.1 Alarm based on trend data to modify procedures to generate less dust (SME)
  6.4.2 Alarm to shut down because operational limits regarding dust have been exceeded (SME)
6.5 Store data (HF)
6.6 Turn system off (HF)

7. HECS/Human (most of the above functions include the HECS as the operating system). The following are those functions/tasks occurring specifically at the HECS.
7.1 Use remote vision for telepresence to provide situation awareness (HF)
  7.1.1 Control camera selection (HF)
  7.1.2 Control tilt/pan/zoom functions (HF)
7.2 Data functions (HF)
  7.2.1 Collect data from remote sensors (HF)
  7.2.2 Transmit data to workstations as necessary (HF)
    7.2.2.1 Person(s) responsible for strategic planning and decision making (HF)
    7.2.2.2 Person(s) responsible for supervision of onsite operations (HF)
    7.2.2.3 Persons responsible for operation of mobile equipment (e.g., conveyance, gantry crane, excavator). (HF)
    7.2.2.4 Person(s) responsible for onsite analysis of geophysical data (HF)
    7.2.2.5 Person(s) responsible for in-town analysis of data (HF)
  7.2.3 Display data (HF)
  7.2.4 Store data (HF)
  7.2.5 Manipulate data (HF)
  7.2.6 Analyze data (HF)
7.3 Collision avoidance functions (HF)
7.4 Alarm functions (HF)
  7.4.1 Advisory warnings of systems that are in danger of experiencing trouble (HF)
  7.4.2 Shutdown warnings (HF)
7.5 Strategic functions (HF)
  7.5.1 Make decisions (HF)
  7.5.2 Plan operations (HF)
  7.5.3 Supervise operations (HF)
7.6 Monitoring functions (HF)
  7.6.1 System operations (HF)
  7.6.2 Contamination control (HF)
  7.6.3 System health (HF)
  7.6.4 Equipment condition (HF)
  7.6.5 Preventive maintenance schedule (HF)

- The following functions/tasks are included in the tasks associated with each individual piece of equipment. They are included here for ease of reference when thinking about all of the kinds of activities that must take place in the HECS

7.7 Control functions (HF)
  7.7.1 Operate mobile equipment (HF)
    7.7.1.1 Operate gantry crane (HF)
      7.7.1.1.1 Perform automated tasks with manipulator arms (e.g., attach/detach various tools in tool storage area) (HF)

7.7.1.1.2 Perform manual tasks with manipulator arms (e.g., manipulate misting equipment) (HF)

7.7.1.1.3 Perform tasks using hoist (HF)

7.7.1.1.4 Perform maintenance tasks (HF)

7.7.1.2 Operate excavator (HF)

7.7.1.2.1 Operate innovative end effector during full-scale retrieval (HF)

7.7.1.2.2 Operate bucket during hot spot retrieval (HF)

7.7.1.2.3 Operate excavator for other tasks (e.g., putting aside a large object) (HF)

7.7.1.3 Operate conveyance (HF)

7.7.2 Control equipment associated with contamination control (HF)

7.7.2.1 Operate equipment associated with misting (HF)

7.7.2.2 Operate equipment associated with shoring (HF)

7.7.2.3. Operate equipment associated with grouting (HF)

7.7.2.4 Operate equipment associated with application of fixant chemicals (HF)

7.7.2.5 Operate equipment associated with the SONSUB (HF)

7.7.2.6 Operate equipment associated with the vacuum (HF)

7.7.2.7 Operate other tools (HF)

7.7.3 Control equipment associated with dust sampling and other forms of air quality sampling (HF)

7.7.4 Control equipment associated with digface characterization (HF)

7.7.4.1 Operate interferometer (HF)

7.7.4.2 Operate ground penetrating radar (HF)

7.7.4.3 Operate hazard group of sensors (HF)

7.7.4.4 Operate geophysical group of sensors (HF)

7.7.5 Control equipment associated with sizing (HF)

7.7.5.1 Operate shears (HF)

7.7.5.2 Operate cryogenic cutting equipment (HF)

Appendix F

Functions, Information Requirements, and Interactions Listings for BWID Equipment

Appendix F

Functions, Information Requirements, and Interactions Listings for BWID Equipment

Equipment: HECS

Function/Task:

Control and monitoring of remote waste retrieval equipment and related data; communication between human operators.

Information Requirements:

- Data and information necessary to plan strategy for waste retrieval, to anticipate effects of a chosen plan, to implement a chosen plan, and to evaluate the results of attempts to implement a chosen plan.
- Status of all systems related to the HECS itself and to the systems operated by the HECS.

Interactions:

Intended: (to be facilitated through design)

- Send commands and receive data from various systems in the containment building and in the HECS.
- Engage in coordinated operations between chief operator using excavator/vacuum and other operator(s) using manipulator arm off gantry crane during excavation operations.
- Real-time motion monitoring/tracking.

Unintended: (to be minimized through design)

- Inaccurate and/or incomplete communications between operators and/or between operators and equipment.
- Exchange of corrupted commands and/or data with equipment in containment building.

Equipment: Remote Vision System

Function/Task:

Provide visual displays and visual feedback to human operators engaged in teleoperation of equipment.

Information Requirements:

- Views required for particular operator and/or particular activity/operation.
- System status.

Interactions:

Intended: (to be facilitated through design)

- Interaction between various personnel for coordinated activities.
- Receive commands and send video signals to meet needs of personnel in HECS.
- Real-time motion monitoring/tracking.

Unintended: (to be minimized through design)

- Collision between fixed-position camera(s) and moving equipment in containment building.
- Collision between camera(s) mounted on one piece of moving equipment with some part of another piece of moving equipment.
- Collision between remote camera operated by manipulator arm and digface or fixed/moveable equipment in containment building.
- Views (tilt/pan/zoom) changed by one operator on a particular camera, without knowledge of all affected by the change, may affect another operator's performance.

Equipment: Gantry Crane

Function/Task:

Manipulate tools used for contamination control and soil/digface characterization, handle vacuum, operate remote cameras for special views.

Information Requirements:

- Position and status of manipulator arms and end effectors (could include information about position of crane and z-mast when relevant, but generally position/status and arm motion range given current position are primary).
- Real-time motion monitoring and tracking.
- System status.

Interactions:

Intended: (to be facilitated through design)

- Receive commands and send data to meet needs of automated systems and to meet needs of personnel in the HECS.
- Engage in coordinated activity with excavator and bucket/end effector/shears during excavation operations.
- Engage in coordinated activity with vacuum during excavation operations.
- Position manipulator arms to allow for attachment, manipulation, and detachment of various tools and sensors.
- Real-time motion monitoring/tracking.

Unintended: (to be minimized through design)

- Collision between gantry crane and/or manipulator arms with end effectors and fixed/moveable equipment in containment building.
- Collision between manipulator arms with end effectors and digface.
- Gantry crane movement without knowledge of all affected in a way that affects another operator's performance.

Equipment: Excavator

Function/Task:
Remove dirt/waste, size objects

Information Requirements:
- Position and status of excavator, and bucket/shear/end effector (as well as boom and stick when needed).
- Real-time motion monitoring and tracking.
- System status.

Interactions:
Intended: (to be facilitated through design)
- Receive commands and send data to meet needs of automated systems and to meet needs of personnel in the HECS.
- Engage in coordinated activity with conveyance during delivery of empty "boxes" and "dumping" of waste material in some way (e.g., detach end effector, place sized material in box, etc.).
- Engage in coordinated activity with gantry crane during retrieval (e.g., camera placement, contamination control efforts).
- Real-time motion monitoring/tracking.

Unintended: (to be minimized through design)
- Collision with fixed/moveable equipment in containment building (e.g., sensor, tool storage area, conveyance, gantry crane).
- Collision with digface (e.g., tipping excavator over).
- Excavator, boom, bucket/end effector/shears moved without knowledge of all affected by movement in a way that affects another operator's performance.

Equipment: Conveyance

Function/Task:
Provide empty boxes/end effectors and receive, transport, off-load dirt/waste material.

Information Requirements:
- Position of conveyance, box, and lid.
- Status of conveyance, box, and lid.
- Status of load (clean, dirty, soil, scrap metal, mixed waste, etc.)
- Desired destination for current/upcoming trip.
- System status.

Interactions:
Intended: (to be facilitated through design)
- Receive commands and send data to meet needs of automated systems and to meet needs of personnel in the HECS.
- Engage in coordinated activity with excavator and bucket/end effector/shears during excavation/sizing operations.

- Engage in coordinated activity with equipment used for contamination control (dust control) on conveyance path.
- Real-time motion monitoring/tracking.

Unintended: (to be minimized through design)

- Collision between conveyance and fixed or moving equipment in containment building.
- Conveyance may drive into area where it does not belong (e.g., too close to the edge of the pit).

Equipment: Contamination Monitoring (Dust Sampling System)

Function/Task:
Monitor dust/particulate type, location, and concentration during excavation and other dust generating activities (e.g., moving excavator or "driving" conveyance); monitor type, location, and concentration of volatile organic chemicals in environment.

Information Requirements:

- Position and status of each sensor in the system.
- Output data (e.g., type, location, concentration of each contaminant).

Interactions:
Intended: (to be facilitated through design)

- Receive commands and send data to meet needs of automated systems and to meet needs of personnel in the HECS.
- Communicate with operators regarding system status when contaminants approach levels that may affect operations.

Unintended: (to be minimized through design)

- Collision between sensor groups and moving equipment within the containment building.

Equipment: Contamination Control

Function/Task:
Suppress dust generation through the use of mist, chemical fixants, sprays, etc.

Information Requirements:

- Dust/particulate type, location, and concentration.
- Historical information regarding current contamination control efforts (e.g., What has been sprayed? What is being sprayed? How much has been sprayed? How often has it been sprayed?).
- Knowledge of available contamination control technologies (e.g., What are they? What are they good for? How are they deployed?).
- Effects (e.g., changes in sensor data) of changes in contamination control strategy.

Interactions:

Intended: (to be facilitated through design)

- Receive commands and send data to meet needs of automated systems and to meet needs of personnel in the HECS.
- Engage in coordinated activity involving manipulator arm and contamination control end effectors during attachment, manipulation, and detachment.
- Engage in coordinated activity involving manipulator arm with contamination control end effector and excavator with bucket/end effector/shears, vacuum, and conveyance.
- Real-time motion monitoring/tracking.

Unintended: (to be minimized through design)

- Collision between manipulator arm with contamination control end effector and other fixed/moveable equipment in containment building.
- Collision between manipulator arm with contamination control end effector and digface.
- Gantry crane may be moved without knowledge of all affected by movement in a way that affects another operator's performance.

Appendix G

Suggestions for FY-95 Technology Interface Improvements

Appendix G

Suggestions for FY-95 Technology Interface Improvements

Because the human engineered control station (HECS) is not funded for FY-95, the HECS team felt that it was important to provide suggestions to each technology on their specific human-machine interface. The suggestions below are given as design options based on the current equipment and software developed for the technology. These designs are by no means optimum but will improve the interface for FY-95. The following technologies are each discussed: excavator, conveyance system, gantry crane and subsystems, and digface characteriazation.

Another issue concerning the FY-95 integrated demonstration is the planned staffing. The final section in this appendix addresses the recommended staffing for the FY-95 integrated demonstration given the current funding proposed. Note that the staffing alternatives given in the report itself are preferred, but based on the limitations currently given in BWID's plan, an alternate staffing is recommended.

G-1. EXCAVATOR

G-1.1 Data Needs

The following data will be required by the excavator operator

Visual information - cameras
Vehicle speed
Direction/movement
Position information - excavator and bucket
System warnings and alarms
Monitoring information (e.g., rad levels, dust level)
Interlock data/status
Engine sounds - other audio
Engine RPM
Fuel level
Engine oil pressure
Engine/coolant temperature
Electronics temperature
Force on bucket/stick/boom
Tilt of excavator
Exhaust system status
Conveyance box location
Conveyance box status - empty/full
ITM coupling status - engaged/disengaged
ITM status - present/not present
Time until greasing
Time until oil filter change

Time until hydraulic oil filter change
Time until air filter change
Other maintenance schedules
Stabilizer/emergency brake status
Broken track
Camera lens cleaner status
Calibration schedules/data
Selected digface characterization information
Other characterization information.

G-1.2 Frequency of Data Use

The most frequently used data should be readily accessible and located right in front of the operator. Therefore, the most frequently used data should be considered in any panel layout as well as any software displays and controls. For the FY-95 integrated demonstration, the most frequently used data will be

Visual information - cameras
Position information - excavator and bucket
Conveyance box location
Conveyance box status - empty/full
ITM coupling status - engaged/disengaged
ITM status - present/not present.

G-1.3 Critical Data Needs

Critical data are that required to maintain safety and equipment integrity. The most critical data should be salient to the operator during excavator use. This may be conflicting with the above frequency of data use discussion but, nevertheless, should take precedence when it makes sense to do so. Some of this information, such as oil pressure, needs to be displayed to the operator only when it is outside normal operating bounds. During a radioactive retrieval operation, the critical data are considered to include

Visual information - cameras
Vehicle speed
Direction/movement
Position information - excavator and bucket
Fuel level
Engine oil pressure
Engine/coolant temperature
Electronics temperature
Force on bucket/stick/boom
Tilt of excavator
Exhaust system status
System warnings and alarms
Monitoring information (e.g., rad levels, dust level)

Interlock data/status
Selected digface characterization information.

G-1.4 Controls and Displays

The suggestions given in this section are based on application of human factors engineering principles to what is known about the human-machine interface for the excavator as it is evolving for the FY-95 demonstration. The design options described in Section 6 of the main report are the recommendations of the HECS team; however, the following suggestions are meant to help improve the less than optimal design approaches evolving for the FY-95 demonstration.

Some method of sensing arm and hand position to control the excavator boom/stick/bucket has been mentioned for the demonstration. Whatever the configuration of this type of control, consideration should be made concerning ergonomics and anthropometrics. Control should be as intuitive as possible. Since the human arm does not joint or move the same as the excavator boom/stick/bucket, it may be most intuitive to control only end effector movement and position using corresponding hand position (boom/stick/bucket angular and spatial relationships should not require cognitive and physical interpolation by the operator). This does not mean that some situational awareness of boom/stick/bucket relationships should not be maintained by the operator, using remote vision or computer modeling, when these relationships may constitute useful information (i.e., special collision avoidance situations).

Special consideration must be given to operator fatigue and potential injury due to repetitive motion (i.e., cumulative trauma) and excessive fatigue. Therefore, the arm should be supported or counterbalanced in some manner to reduce physical stress, with the movement ranges small, anthropometricaly correct, and requiring little force.

Unless completely linked to end effector positioning and thus automatic, the task of driving and positioning of the excavator should be performed in a manner cognitively and physically different than end effector control. An intuitive means of moving/positioning the excavator such as forward/rotate left/rotate right/reverse corresponding to similar joystick inputs must be provided. Speed could be a function of the amount of joystick deflection. The proper camera views must be provided for driving/positioning, must be easily selectable, and provide salient cues concerning appropriateness of selected view for the desired movement. Computer model displays (e.g., bird's eye view) could provide additional and uncluttered position information to the operator. Relevant critical parameters for driving/positioning (e.g., speed, direction, obstacle location/proximity) should be displayed in the remote vision camera view being used. Such parameter displays should be intuitive and simple (e.g., icon labels, color coded ranges with little or no alpha numerics).

Frequently needed and critical data should be displayed to the operator at the appropriate time relative to task and situation. Display by CRT would provide maximum flexibility. Parameter displays (whether CRT or panel based) should be simple, intuitive, well labeled, provide color coded ranges when appropriate, and be grouped according to function. Any icons or abbreviations used must be well understood by, and familiar to, the operator. If panel based, as well as being functionally grouped, displays should be arranged for logical scan patterns. If CRT based, display navigation and access should be designed to be simple (at most one or two selections required) with needed data always displayed during task performance. Specific data should be provided in the remote vision display when operator attention is focused on the remote vision display and the data are needed or critical for the task or situation (e.g., excessive excavator tilt, warnings and alarms). Audio warnings/alarms should be presented with associated visual warning/alarms.

There are guidelines given for ranges of adjustability for computer applications such as this one.[1] In summary, the computer screen height (from floor to center of screen) should be adjustable between 33 and 42 in. for a sitdown workstation. The keyboard height (from floor to center height of keyboard) should be adjustable between 25 and 31 in. The table height (from floor) should be adjustable between 26 and 32 in. The angle of the screen should be adjustable for up/down tilt of 0 to 7 degrees (0 degrees is screen perpendicular to the table). The viewing angle at where the operator looks at the screen should be 15 to 25 degrees (0 degrees would be straight ahead). The viewing distance (from the operator's eyes to the screen should be 15 to 30 in.). The elbow angle should be 90 degrees to stroke the keyboard. The seat height should be 15 to 20 in. The angle from the seat to the seat back should be 100 to 120 degrees. In addition, if a footrest is used, the toe height should be 4 in., and the heel height should be 1 to 2 in.[1]

G-1.5 Issues

Information regarding the form of the excavator human-machine interface for the FY-95 demonstration is limited at this point. Therefore, detailed and specific human engineering recommendations for the interface (in lieu of the recommended design options in Section 6 of the main report) cannot be given. Nevertheless, the recommendations given in Section G-1.4 above are valid and useful and based on considerable information about the excavator and excavator tasks for BWID.

Integration of the excavator with other BWID systems for the demonstration is not being considered in a systematic or complete manner. Given this, even some of the suggestions given above for improving a less than optimum human-machine interface may not be able to be implemented. One example is the recommended collision avoidance display elements to provide adequately complete collision avoidance information for the operator. Such display elements could not be provided because a hardware/software positioning system that could provide detailed collision avoidance information will probably not be implemented for the demonstration. Another example is characterization information. Since various characterization information will not be available on-line, the excavator operator should ask the characterization team for relevant information.

G-2. CONVEYANCE

G-2.1 Data Needs

The following data will be required by the conveyance operator:

Visual information - cameras
Vehicle speed
Direction/movement
Position information - with respect to building, other equipment, configuration
System warnings and alarms (e.g., collision, status, weight)

Monitoring information (e.g., rad levels, dust level)
Box empty/full
Box weight
Lid position and latch status
ITM loaded in WTC - yes/no
ITM in cradle (external) - yes/no
WTC loaded and locked - status
Roller table status
Interlock data/status (e.g., obstacle proximity stop, lid position)
Engine sounds - other audio
Engine RPM
Fuel level
Engine oil pressure
Engine/coolant temperature
Electronics temperature
Tilt of conveyance
Exhaust system status
Time until greasing
Time until oil filter change
Time until hydraulic oil filter change
Time until air filter change
Other maintenance schedules
System health monitoring data
Stabilizer/emergency brake status
Broken track
Camera lens cleaner status
Calibration schedules/data.

G-2.2 Frequency of Data Use

The most frequently used data should be readily accessible and located right in front of the operator. Therefore, the most frequently used data should be considered in any panel layout as well as any software displays and controls. For the FY-95 integrated demonstration, the most frequently used data will be

Visual information - cameras
Vehicle speed
Direction/movement
Position information - with respect to building, other equipment, configuration
Box empty/full
Box weight
Lid position and latch status
ITM loaded in WTC - yes/no
ITM in cradle (external) - yes/no
WTC loaded and locked - status.

G-2.3 Critical Data Needs

Critical data are that required to maintain safety and equipment integrity. The most critical data should be salient to the operator during excavator use. Some of the data, such as oil pressure, needs to be displayed to the operator only when it is outside normal operating bounds. This may conflict with the above frequency of data use discussion but, nevertheless, should take precedence when it makes sense to do so. During a radioactive retrieval operation, the critical data are considered to include

Visual information - cameras
Vehicle speed
Direction/movement
Position information - with respect to building, other equipment, configuration
System warnings and alarms (e.g., collision, status, weight)
Monitoring information (e.g., rad levels, dust level)
Interlock data/status (e.g., obstacle proximity stop, lid position)
Engine sounds - other audio
Engine RPM
Fuel level
Engine oil pressure
Engine/coolant temperature
Electronics temperature
Tilt of conveyance
Exhaust system status
Time until greasing
Time until oil filter change
Time until hydraulic oil filter change
Time until air filter change
Other maintenance schedules
System health monitoring data
Stabilizer/emergency brake status
Broken track
Camera lens cleaner status
Calibration schedules/data.

G-2.4 Controls and Displays

All important task related information should be displayed while the task is being performed. Supplemental information should be easily accessed when it is needed. Parameter displays (whether CRT or panel based) should be simple, intuitive, well labeled, provide color coded ranges when appropriate, and be grouped according to function. Panel displays as well as being functionally grouped could be arranged for logical scan patterns. Any icons or abbreviations used must be well understood by, and familiar to, the operator.

Parameters and information important to moving/driving/positioning the conveyance should appear in the remote vision camera display being used by the operator (in a "heads up" type presentation). The human-machine interface evolving for the FY-95 demonstration seems to incorporate a transparent target display overlaid on the remote vision camera display that corresponds to a target form on the excavator. In theory, the operator is aided in correctly positioning the conveyance in relation to the excavator by moving the conveyance so the target overlay and target form match (and observing specific dynamic visual symbology cues and digital coordinates in the overlay target). This approach appears to be nonintuitive, as well as perceptually and cognitively demanding, and requires further assessment before a recommendation can be made here regarding its use. A computer model overview (such as a bird's eye view) incorporating simple excavator and conveyance representations with simple positioning cues (e.g., box, arrows) would be more intuitive with less cognitive and perceptual complexity. Given the lack of a positioning system and computer model, a bird's eye camera view with position cues overlaid may provide a less complex and demanding operator task than the target system.

As discussed above for the excavator (Section 1.4), an intuitive means of moving/positioning/driving the conveyance such as forward/rotate left/rotate right/reverse, corresponding to similar joystick inputs, must be provided. Speed could be a function of amount of joystick deflection. The proper camera views must be provided for driving/positioning, must be easily selectable, and provide salient cues concerning appropriateness of selected view for the desired movement. Camera pan and tilt could be controlled by a thumb controlled nipple (spring loaded to center thus returning camera to forward) on top of the (pistol grip) joystick. With this control configuration, it would be natural for the operator to precede a turn with camera pan and allow the camera to return to forward as the turn completes. Camera zoom could be controlled by a slide (also spring loaded to neutral) mounted on the joystick or joystick base.

There are guidelines given for ranges of adjustability for computer applications such as this one.[1] In summary, the computer screen height (from floor to center of screen) should be adjustable between 33 and 42 in. for a sitdown workstation. The keyboard height (from floor to center height of keyboard) should be adjustable between 25 and 31 in. The table height (from floor) should be adjustable between 26 and 32 in. The angle of the screen should be adjustable for up/down tilt of 0 to 7 degrees (0 degrees is screen perpendicular to the table). The viewing angle the operator looks at the screen should be 15 to 25 degrees (0 degrees would be staight ahead). The viewing distance (from the operator's eyes to the screen should be 15 to 30 in.). The elbow angle should be 90 degrees to stroke the keyboard. The seat height should be 15 to 20 in. The angle from the seat to the seat back should be 100 to 120 degrees. In addition, if a footrest is used, the toe height should be 4 in. and the heel height should be 1 to 2 in.[1]

G-2.5 Issues

As with the excavator, information regarding the form of the conveyance human-machine interface for the FY-95 demonstration is limited at this point. Therefore, detailed and specific human engineering recommendations for the interface (in lieu of the recommended design options in Section 6 of the main report) cannot be given. Nevertheless, the recommendations given in G.2.4 above are valid and useful, and based on considerable information about the conveyance and conveyance tasks for BWID.

Integration of the conveyance with other BWID systems for the demonstration is not being considered in a systematic or complete manner. Given this, even some of the suggestions given above for improving a less than optimum human-machine interface may not be able to be implemented. An example is the suggested bird's eye view computer model or camera view with position cues to aid the operator in positioning the conveyance in relation to the excavator. A hardware and software positioning system would help automatically generate the appropriate positioning cues for the displays but will probably not be available or implemented for the demonstration.

G-3. GANTRY CRANE AND SUBSYSTEMS

G-3.1. Data Needs

The following data will be required by the gantry crane operator:

Speed arms/hoists/crane
Direction/movement arms/hoists/crane
Visual information - cameras
Noise from crane and other equipment in building
Position information with respect to building, other equipment, configuration, electronics temperature
Box empty/full
Box location
Time until greasing required
Warning if crane is too close to an obstacle
On/off status
System health monitoring data
Characterization data - from characterization team
Sensor too close to digface
Sensor control/offset
Scan rates - characterization tools - desired and actual
Scan paths - characterization tools and contamination control
Data file names
Sensor connections yes/no
Grout retrieval bucket connections yes/no
Contamination control connections yes/no
Status of contamination control sprays/mists/foams (amount)
Status of pumps for contamination control
Spray rates (dust suppression and fixant)
Spray direction
Spray pattern
Compressor pressure for misting systems
Vacuum connection yes/no
How full the vacuum is
Location of each tool
Location of where to apply tool
Overall monitoring data in the structure
Calibration of all tools and sensors - schedule and values
Maintenance of all tools and sensors - schedule

System warnings and alarms
Interlock data/status
Emergency stop.

G-3.2 Frequency of Data Use

The most frequently used data should be readily accessible and located right in front of the operator. Therefore, the most frequently used data should be considered in the panel layout as well as the software displays and controls. For the FY-95 integrated demonstration, the most frequently used data will be

Speed arms/hoists/crane
Visual information - cameras
Position information with respect to building, other equipment, configuration
Direction/movement
Box empty/full
Box location
On/off status
Location of each tool
Location of where to apply tool.

G-3.3 Critical Data Needs

The most critical data should be salient to the operator during gantry crane use. This may be conflicting with the above frequency of data use discussion but, nevertheless, should take precedence when it makes sense to do so. During a radioactive retrieval operation, the critical data are considered to include

Visual information - cameras
Warning if crane is too close to an obstacle
Sensor too close to digface
Overall monitoring data in the structure
Maintenance of all tools and sensors - schedule
System warnings and alarms
Interlock data/status
Emergency stop.

G-3.4 Controls and Displays

The suggestions provided in this section are based on good human factors principles applied to the existing gantry crane control station design. Therefore, these are suggestions to improve the existing interface design based on schedule, cost, and existing equipment. These quick and dirty fixes are by no means optimum (see Section 6 of the main report) but will improve the human-machine interface for the FY-95 demonstration. These suggestions are organized from an overall layout of the control station down to specific software and control suggestions.

a. Control Panel Design. The current panel design is shown in Figure 1 below. The panels are black.

A more appropriate color would be a light gray or blue panel. In addition, the dimensions of the panels do not lend themselves to anthropometic guidelines. Anthropometrics refers to measurement of the dimensions and other physical characteristics of the body. Both static positioning and dynamic movements should be considered during a design. There are three principles of applying anthrompometric data to designs that are typically used. These are (1) design for extreme individuals (meaning tallest or shortest, etc.), (2) design for adjustability (provide a range), and (3) design for the average person. The best design principle is to design for adjustability. Typically, designs cover the range from the 5th to 95th percentile of the relevant population characteristic. See discussion below on control panel layout for specifics regarding the adjustability range suggested for the work station design.

b. Control Panel Layout. The current panel layout is shown in Figure 2.
A more appropriate panel would be adjustable. For example, in addition to having adjustable chairs, the distance the table of the panel is from the floor should be adjustable. In addition, within the panel itself, the monitors (video and CRTs) should be able to be adjusted on a roller type stand so that they can be adjusted to tilt up, down, left, or right. There are guidelines given for ranges of adjustability for computer applications such as this one.[1] In summary, the computer screen height (from floor to center of screen) should be adjustable between 33 and 42 in. for a sitdown workstation. The keyboard height (from floor to center height of keyboard) should be adjustable between 25 and 31 in. The table height (from floor) should be adjustable between 26 and 32 in. The angle of the screen should be adjustable for up/down tilt of 0 to 7 degrees (0 degrees is screen perpendicular to the table). The viewing angle the operator looks at the screen should be 15 to 25 degrees below horizontal (0 degrees would be staight ahead). The viewing distance from the operator's eyes to the screen should be 15 to 30 in. The elbow angle should be 90 degrees to stroke the keyboard.

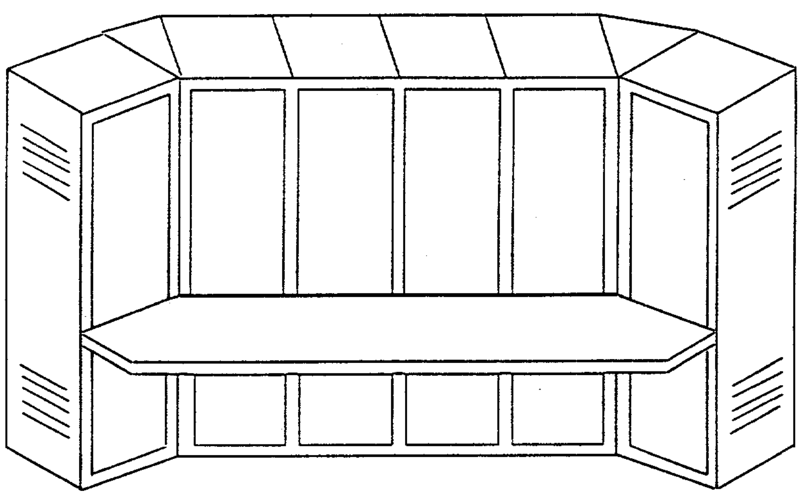

Figure 1. Current gantry crane control panels.

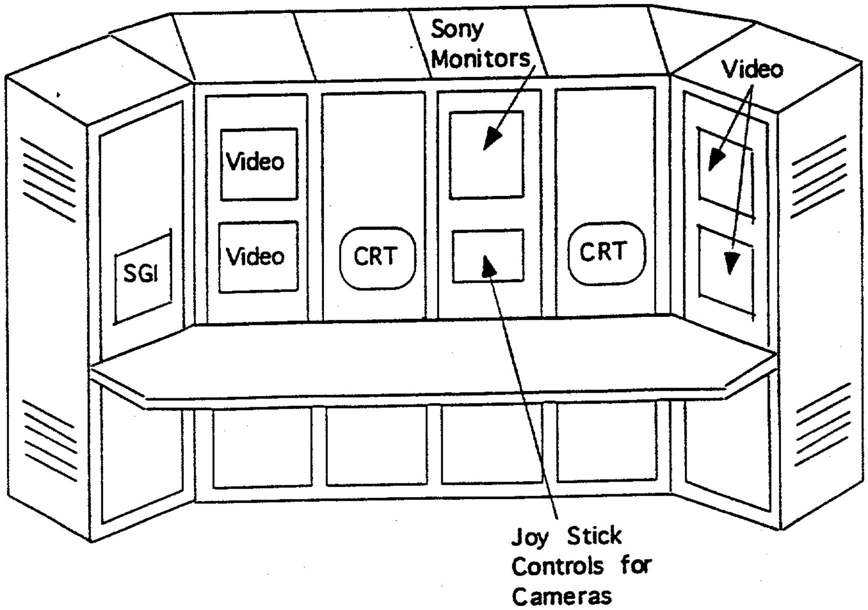

Figure 2. Current gantry crane panel layout.

The seat height should be 15 to 20 in. The angle from the seat to the seat back should be 100 to 120 degrees. In addition, if a footrest is used, the toe height should be 4 in. and the heel height should be 1 to 2 in.[F-1] Another concern is how to show multiple camera views and allow the operators to keep track of which view they are seeing. The current design allows for two views at one time on the TV monitors. Between the operators, a panel with all ten views (very small) is housed. We suggest at a minimum that the operators should be able to know which camera they are viewing. To enhance flexibility in the system, if only two TV monitors are going to be used, it would be advantageous to allow each monitor to display several camera views at any given time. The operator should be able to specify how many views they would like on each monitor and which camera views should be on which monitors. This flexibility would be advantageous during testing since the best views and optimum number of views is unknown until the equipment has been used in the field. The selection of views could be done from a screen on the CRT, on an instrument panel, or by a remote controller similar to a television remote controller. Another suggestion is to put information on the bottom of the video screens to identify which camera is currently being viewed. Without this information, the operator could become disorientated because there are ten camera views that will be available.

c. Software Changes. The current software offers flexability. The SGI can show a 3D model of the gantry crane and the two terminals can show a 3D wire model of the gantry crane.

On the main screen used for gantry control, the top portion of the screen offers a table with the Mechanisms (Bridge, Arm 1, Arm 2, Trolley 2, and Hoist), Control (Released, Force Ball, or Teach Pendant), TCF (tcf, b1tcf, tcf1, tcf2, and tcf3), and Target (tcf, b1tcf, tcf1, tcf2, and tcf3). We suggest the title "TCF" be changed to Target Control Frame and the title "Target" be changed to Reference Frame. Within these (TCF/Target Control Frame and Target/Reference Frame) categories, the choices offered should also be renamed to aid in recognition of these choices. The choice "tcf" should be renamed to "gripper" because it corresponds to the end of the gripper. The choice "b1tcf" should be renamed to "Arm Base" because it refers to the based of the arm. It is our current understanding that tcf1, tcf2, and tcf3 do not have a corresponding coordinate location. So they should be removed from the list. In addition, the choice "World" should be added to the list. Any other additions that are determined to be required should be named in a similar fashion.

On the current software system, when one of the mechanisms is to be moved in a frame, jog, or joint mode, a window with the appropriate mechanism is listed with joints and numbers that can be adjusted up and down. We offer several suggestions here to aid in the position adjustment of the various mechanisms. First of all, there are no units associated with the numbers. It is our understanding that these can be degrees, radians, inches, etc. It would be beneficial to include these units. In addition, the control of the numbers up is accomplished by pushing the left mouse button over either the left or right arrow next to the number and by adjusting the numbers down, the right mouse button is utilized. Figure 3 shows this current layout.

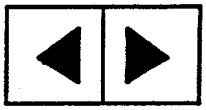

Figure 3. Current arrow adjustment for positioning mechanisms.

We recommend that the mouse button (either one) be depressed on the appropriate arrow to manipulate the value to position the end effector. In addition, we recommend that the arrows be changed to the configuration shown in Figure 4. This configuration better showns that values are being adjusted up or down.

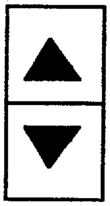

Figure 4. Recommended arrow adjustment configuration.

In addition, the current configuration in these mechanism adjustment windows shows the values next to J1, J2, etc. It is our interpretation that these refer to joints on the mechanism. These joints should be pictured on the model as J1, J2, etc., so that the operators know which joint they are adjusting. By following this logic, the joints will have to be labeled sequentially, thus there will not be a J1 for both the bridge and the arm1, etc. This can reduce error in the event of an emergency and may increase productivity. Likewise, the cameras that are adjusted should be shown on the model as C1, C2, etc.

At the bottom of the main screen, the operator has the ability to select a path. We recommend that several paths be available to the operator. These should include pickup of the characterization tools, shears, contamination control hoses, vacuum, selective retrieval tools, grouting retrieval bucket, as well as preprogrammed paths for pit survey and spraying contamination control for the conveyance system on its path. The path names should reflect the tool name to be retrieved (rad sensor, geophysical tools, vacuum, hoses, etc.) or the activity (spray path and survey pit). In addition, the points associated with the path should be easily understood. An example may be "move to tool area," "get vacuum," etc. The flexibility that the program offers for programming points and paths is extremely valuable, but all known repeated paths should be preprogrammed into the system.

Another issue, although minor, would be to add the flexibility to being able to move any window to the front of the screen. Currently, the more detailed window must be on top. Related to this, the system offers the flexibility of enlarging a window but not reducing the size of the window. With the number of windows that may be open at any given time, it may be nice to size the windows so that only a portion of the window is seen.

We strongly recommend that the model be used during the demonstration. The model can offer important information, and during position adjustment can show the joints or camera locations. This information is invaluable.

Another important addition to the software would be a click and move function. Using the gantry crane computer model, it would be desirable if the operator could use the mouse to click in the direction in which to move. For instance, if an arm is needed to move a barrel, but the gantry crane is located elsewhere, the operator would cause the gantry to move to the barrel and stop. In order to implement a click and move function given the constraints of time, cost, and hardware limitations, it would be advisable to design the function to move the crane in the general direction only. Once the crane is in the vicinity, it could be moved to position using the jog, frame, or joint mode. With this scenario, the function still saves the operator valuable time and is also practical for the FY-95 demonstration.

d. Other Suggestions

Currently, a force ball (approximately softball sized) with wrist rest is planned for moving/controlling the manipulator arms. The currently proposed forceball may be less than optimal in two human factors areas: (1) anthropometrics and (2) feedback. In terms of anthropometrics, the large size of the ball seems to require a hand position that is less than natural and somewhat extreme in terms of finger spread. This could lead to fatigue and possible cumulative trauma disorders in the hand and wrist. Also the static nature of the forceball will result in full input forces being transmitted to hand and wrist structures. This could increase the probability of developing cumulative trauma disorders. An input device that moves and turns easily in response to applied force would result in less force transmitted to the hand and wrist structures. A smaller ball would provide a more natural grasp and tend to reduce cumulative trauma effects.

In terms of feedback to the user's hand, the proposed forceball provides feedback only in terms of the amount and direction of force applied by the hand and provides no feedback in terms of relative movement associated with the applied force. More intuitive feedback would be provided if forces to the controller resulted in appropriate controller deflection and movement. Such a controller would also provide visual feedback to the operator regarding the results and amount of force applied.

A suggested configuration for the controller would be a small ball (1 to 1.5 in. diameter) atop a small stick/joystick. The stick/joystick should allow free ball movement in all directions (including up and down vectors). The mechanism could be slightly spring loaded to center and provide increasing force feedback as deflection increases. Forces should be designed to provide meaningful feedback dues without inducing significant forces or fatigue. The ball could be designed to rotate in all directions (or specific relevant directions, i.e., rotation around z axis to rotate manipulator gripper and rotation around x axis to deflect joint closest to gripper) and also be spring loaded to center with appropriate feedback forces as described above for the stick.

Visual feedback should be provided in the remote vision camera displays and computer displays to augment feedback from the controller and provide situation awareness concerning end effector position and movement. Additionally, ticks or carets on color (or shape) coded ranges could be provided, overlaid on the remote vision camera display and on the computer displays depicting/providing feedback for controller deflection/force in response to user input to the controller.

A wrist or arm rest should be provided and positioned to allow natural and primarily neutral hand and wrist positioning during controller use. The arm support could be articulated or otherwise allow elbow and arm movement to facilitate neutral wrist positioning. Controller movements should be relatively small with minimum forces only large enough to provide meaningful feedback.

The new controller described is conceptual and has never been implemented as far as is known. Some testing and research to confirm useability and function would be required. For example, incorporating the movable ball atop the joystick may be introducing degrees of freedom that could induce error (e.g., inadvertently moving ball when moving joystick) and may be nonintuitive. An alternative would be to design the task as a two hand operation, using two controllers, and separating functions (i.e., using one hand for end effector movement; using the other hand for gripper rotation, and movement of the joint closest to the gripper).

G-3.5 Issues

The issues associated with the above recommendations include

- No integration of characterization information
- No collision avoidance
- All data need not currently addressed/displayed will need to be added.

Overall issues with the current system, include the use of small screens. There will be a lot of data that will be displayed, and if larger screens can be purchased (17, 19, or 21 in.), it would be easier on the operator. Such a purchase could reduce operator fatigue due to eye strain.

G-4. DIGFACE CHARACTERIZATION

G-4.1 Data Needs

The following data will be required by the characterization team. Some of the data will also be required by other operators and staff.

Geophysical group data:
Soil conductivity corrected for distance
Magnetic field strength
Magnetic field gradient

Hazard group data:
Gamma field in disintegrations/time
Neutron field in disintegrations/time
VOC levels in PPM

General:
Data coordinates (e.g., position tags)
Data time stamps/tags
Sensor coordinates (position)
Sensor movement/direction/speed/path
Digface profile
Ambient temperature
Sensor group temperature
System status
- Collision warning
- Temperature alarms
- Sensor level alarms
- Network status

Calibration schedule.

There is a need for both real-time and post-processed data displays. Hardcopy displays will be available. The digface characterization system needs to receive, archive, display, and allow for manipulation of data, as well as maintain sensor configuration software.

G-4.2 Frequency of Data Use

The most frequently used data should be readily accessible and located right in front of the characterization team or operator. Therefore, the most frequently used data should be considered in any panel configuration as well as any software displays and means of data manipulation. For the FY-95 integrated demonstration, the most frequently used data will be

Geophysical group data (see Section 4.1)
Hazard group data (see Section 4.1)
Data coordinates (e.g., position tags)
Data time stamps/tags
Digface profile.

G-4.3 Critical Data Needs

Critical data are that required to maintain safety and equipment integrity. The most critical data should be salient to the characterization team or operator during use. This may be conflicting with the above frequency of data use discussion but, nevertheless, should take precedence when it makes sense to do so. During digface characterization scans for a radioactive retrieval operation, the critical data are considered to include

Sensor coordinates (position)
Sensor movement/direction/speed/path
Digface profile
Ambient temperature
Sensor group temperature
System status
  Collision warning
  Temperature alarms
  Sensor level alarms
  Network status
Calibration schedule.

G-4.4 Controls and Displays

The suggestions given in this section are based on application of human factors engineering principles to what is known about the human-machine interfaces for the digface characterization team and operator (operator will likely be a gantry crane operator) as they are evolving for the FY-95 demonstration. The design options described in Section 6 are the recommendations of the HECS team; however, the following suggestions are for design approaches evolving for the FY-95 demonstration.

Information and controls needed by the gantry crane operator should be located immediately in front of the operator. If the gantry crane console is used, suggestions from Section 3 are applicable. In addition to the interface needed to operate the crane and manipulator arms (Section 3), scan path, scan rate, sensor offset, and appropriate sensor information is required. The geophysical and hazard group data may also be needed by the operator depending on the level of real-time interactions between the operator and the characterization team, and depending on the level of operator knowledge and real-time intervention requirements based on digface characterization data being collected. Based on the current designs, the HECS team recommends close communication between the gantry crane operators and digface characterization team, with primarily operating information being displayed to the gantry crane operators.

Display of digface characterization system parameter data (and characterization data) to the operator would be most flexible if CRT based. Selected information needed while the operators attention is focused on the remote vision camera display should appear in that display in a "heads up" type presentation. Other task relevant parameter and characterization data/information should be appear in a second CRT (not vision display) in front of the operator. Noncritical or supplemental data/information should be immediately available from the second CRT when needed by the operator. Warnings and alarms should appear (only when appropriate/active) in both the remote vision camera display and the second CRT. Audio warnings/alarms should be presented with associated visual warning/alarms. Parameter and data displays should be simple, intuitive, well labeled, functionally grouped, contain color coded ranges (when appropriate), and minimize use of alphanumeric characters when possible. Any icons or abbreviations used must be well understood by, and familiar to, the operator. If display navigation is required, access should be designed to be simple (at most one or two selections required) with needed data always displayed during task performance. Hard copy color displays (generated by the characterization team) for use by the characterization/gantry crane operator should be designed to correspond intuitively with characterization/gantry crane/manipulator controls and displays used in responding to the hard copy (e.g., same terminology, symbology, color coding, and general format).

Control of digface characterization systems/components (that are not controlled by gantry crane/manipulator arm controls) should be accomplished from CRT displays when possible to minimize the number of control devices the operator must interact with. Control displays should be intuitive with the needed feedback inherent in the control display or displayed in immediate proximity to the control and in heads up fashion (in remote vision camera display) when appropriate.

Characterization team workstations should have ability to display all geophysical and hazard group characterization data (Section 4.1 above) as well as any general digface characterization data (Section 4.1 above) needed for data analysis. Displays designed for the characterization team workstations should be designed to support visualization of the 3D nature of digface characterization data. Workstations and displays should allow meaningful manipulation of the data to facilitate appropriate visualizations/analyses. Methods of data manipulation should be as intuitive and simple as possible. The ability to overlay different relevant data sets for the same characterization area should be possible, with display characteristics that allow visualization of relevant relationships demonstrated by data set overlay. The characterization workstations should allow development by the characterization team of special and standardized type data/information displays for transmitting information/knowledge to operators or other staff in the form of hard copy or eventually on a CRT display. Archive and retrieval functions should be straight forward with simple intuitive indexing and search functions.

G-4.5 Issues

Information regarding the form of the digface characterization human-machine interface for the FY-95 demonstration is limited at this point. Therefore, detailed and specific human engineering recommendations for the interface (in lieu of the recommended design options in Section 6 in the main report) cannot be given. Nevertheless, the recommendations given in Section 2.4 above are valid and useful, and based on considerable information about the digface characterization system and tasks for BWID.

Integration of the characterization with other BWID systems for the demonstration is not being considered in a systematic or complete manner. Because interactions between the digface characterization team, characterization/gantry crane operator, excavator operator, and other staff are important to the remote retrieval mission, a more formal system integration effort is required to provide additional detail in proposed design options and recommendations for the human-machine interfaces.

G-5. DUST MONITORING

G-5.1 Data Needs

The following data will be required by the monitoring operator:

Dust monitoring system parameters/status
Dust monitoring sensors position/direction
Dust monitoring data (position, size, and concentration)
Remote vision of dust source/area and possibly of dust monitoring system
Dust monitoring system maintenance schedule
Calibration schedules/data.

G-5.2 Frequency of Data Use

The most frequently used data should be readily accessible and located right in front of the operator. Therefore, the most frequently used data should be considered in any panel layout as well as any software displays and controls. For the FY-95 integrated demonstration, the most frequently used data will be

Dust monitoring system parameters/status
Dust monitoring sensors position/direction
Dust monitoring data (position, size, and concentration)
Remote vision of dust source/area and possibly of dust monitoring system.

G-5.3 Critical Data Needs

Critical data are that required to maintain safety and equipment integrity. The most critical data should be salient to the operator during excavator use. This may be conflicting with the above frequency of data use discussion but, nevertheless, should take precedence when it makes sense to do so. During a radioactive retrieval operation, the critical data are considered to include

Dust monitoring system parameters/status
Dust monitoring system maintenance schedule
Calibration schedules/data.

5.4 Controls and Displays

The suggestions given in this section are based on application of human factors engineering principles to what is known about the human-machine interface for monitoring as it is evolving for the FY-95 demonstration. The design options described in Section 6 are the recommendations of BWID human factors staff; however, the following suggestions are meant to help improve the less than optimal design approaches evolving for the FY-95 demonstration.

The dust monitoring system (as described to this point) will not be moved by remote control but will be positioned and moved by hand. Therefore no displays and controls will be needed for remote moving/positioning unless a second operator is used to aid positioning remotely. Displays will be needed for the data listed above (Section 5.1) and controls may be required for system parameters that need to be remotely manipulated by the operator (e.g., on/off, sensor levels). Controls may also be needed for handling dust monitoring data (e.g., archive, retrieve, send).

Display of system parameter data and monitoring data to the operator would be most flexible if CRT based. Parameter and data displays should be simple, intuitive, well labeled, functionally grouped, contain color coded ranges (when appropriate), and minimize use of alphanumeric characters when possible. Any icons or abbreviations used must be well understood by, and familiar to, the operator. If display navigation is required, access should be designed to be simple (at the most one or two selections required) with needed data always displayed during task performance. Control displays should be intuitive with the needed feedback inherent in the control display or displayed in immediate proximity to the control and in heads up fashion (in remote vision camera display) when appropriate.

G-5.5 Issues

Integration of dust monitoring with other BWID systems for the demonstration is not being considered in a systematic or complete manner. Because interactions between dust monitoring and the gantry crane operator, excavator operator, conveyance operator, and other staff are important to the remote retrieval mission, a more formal system integration effort is required to provide additional detail in proposed design options and recommendations for the human-machine interface.

G-6. STAFFING

Another issue concerning the FY-95 integrated demonstration is the planned staffing. This section addresses the recommended staffing for the FY-95 integrated demonstration given the current funding proposed. Note that the staffing alternatives given in the report itself are preferred, but based on the limitations currently given in BWID's plan, an alternate staffing is given.

Given the above equipment, it is recommended to have the following staff: four equipment operators, one characterization team, one supervisor, and one supervisor's assistant are recommended. Each staff member has specific areas of responsibility and is expected to maintain situation awareness, and to respond to warnings and alarms as needed. Following is a discussion on each of the proposed staff's responsibilities. In addition to these staff members, personnel would need to be available for routine and nonroutine maintenance, calibration of equipment, recording test data, and other project activities.

G-6.1 Supervisor

This individual will be responsible for directing all HECS operations. The supervisor will plan and coordinate strategy for waste removal/retrieval efforts and will oversee and coordinate the activities of all HECS personnel. The supervisor will also allocate equipment resources between competing activities when necessary (e.g., needing the gantry crane at two places at once). On occasion, this person will request additional information from project directors for strategic decision making. This individual will possess the expertise needed to use all information provided by the characterization team, operators, and supervisor's assistant. The supervisor will maintain situation awareness of the system as a whole.

G-6.2 Supervisor's Assistant

This individual will assist the supervisor in carrying out the supervisor's duties. The supervisor's assistant will be responsible for monitoring system status for all systems, in particular the systems for which none of the operators have responsibility (e.g., the contamination control tanks). The supervisor's assistant will use the system status information to plan for calibration and maintenance activities (either off shift or during the day). The assistant supervisor would also be responsible for ensuring that the tests are performed in accordance with the FY-95 Integrated Test Plan.

G-6.3 Head Gantry Crane Operator

This individual will remotely operate the gantry crane, its manipulator arms, and all of the tools or equipment that may be deployed off of the crane or by the manipulator arms. The head gantry crane operator will receive direction from the supervisor on when, where, and how to deploy equipment. The head gantry crane operator will receive direction from the characterization team on geometries for deploying the characterization equipment. The operator will interface with the characterization team lead, as necessary, to define what waste will/is being retrieved. This individual will also assist the supervisor in directing the activities of the second gantry crane operator. The head gantry crane operator will also monitor system status of the gantry crane equipment. The head gantry crane operator should only be allowed to operate one manipulator arm or hoist at a time, unless a cooperative task, requiring both arms, is being performed.

G-6.4 Second Gantry Crane Operator

This individual will assist in remotely operating the gantry crane, its manipulator arms, and all of the tools or equipment that may be deployed off of the crane or by the manipulator arms. The second gantry crane operator will receive direction from the head gantry crane operator on when, where, and how to deploy equipment. The second gantry crane operator will receive direction from the head crane operator for deploying the characterization equipment. The second gantry crane operator will also monitor system status of the gantry crane equipment. The second gantry crane operator should only be allowed to operate one manipulator arm or hoist at a time.

G-6.5 Conveyance Operator

This individual will remotely operate the conveyance system. The conveyance operator will receive direction from the supervisor, head gantry crane operator, and/or excavator operator on when, where, and how to deploy conveyance equipment. The conveyance operator will also monitor system status of the conveyance equipment.

G-6.6 Excavator Operator

This individual will remotely operate the excavator system. The excavator operator will receive direction from the supervisor on when, where, and how to deploy excavator equipment. The excavator operator will also monitor system status of the excavator equipment. The excavator operator will interface with the characterization team lead, as necessary, to define what waste will or is being retrieved.

G-6.7 Characterization Team

These individuals will plan both routine and nonroutine site/dig-face characterization scans; inform the head gantry crane operator about needed characterization deployment; will consult with engineers as needed concerning the current dig-face and any special needs for information; will analyze, interpret, and display site/dig-face characterization data to provide information to supplement that available through automated displays; and will communicate conclusions to the other HECS operators and others who need to know. The characterization team will also monitor system status of sensors used in the characterization process.

G-7. REFERENCE

1. M. S. Sanders and E. J. McCormick, *Human Factors in Engineering and Design*, Sixth Edition, McGraw-Hill Book Company, copyright 1987.

Appendix H

Possible Equipment Case Vendors

Appendix H

Possible Equipment Case Vendors

Thermodyne International LTD
20850 S. Alameda St., Long Beach, CA 90810
310-603-1976
Rugged, mobile equipment cases (Rack Pack), 19 in. wide, shock isolated

Zero Plastics
672 Fuller Road, Chipopee, MA 01020
413-592-5188
Rugged, portable, shock isolated, rack mount cases/containers

Anvil Cases
15650 Salt Lake Ave., City of Industry, CA 91745
1-800-359-2684 for free catalog

SKB Corporation
434 West Levers Place, Orange, CA 92667
1-800-654-5992
Light, medium, and heavy duty cases, stackable, 2-12 space, rackmount cases

Hardigg Industries, Inc.
393 No. Main St., P.O. Box 201, South Deerfield, MA 01373
413-665-8061
Rack mountable, stackable, shock mounted, double entry containers. Sizes up to 45.62 in. high, 19 in. wide, 23 in. deep

AAR Skydyne
21 River Road, Port Jervis, NY 12771
914-856-6655
19 in. rack mount, shock isolated cases
Sizes up to 21.12 in. ID height, 19 in. × 19 in. wide and deep
Also available in depths up to 30.00 in. ID

ECS Composites
3560 Rogue River Highway/POB 188, Grants Pass, OR 97526
503-476-8871
19 in. Rack mount cases, EMI/RFI shielded products

Appendix I

Cooling Loads for the Human Engineered Control Station

Appendix I

Cooling Loads for the Human Engineered Control Station

I-1. CONTROL ROOM

- The cooling load that has been approximated takes into account the heat conducted through the exterior walls and roof of the control room and geophysics room, heat conducted through the windows, solar gain through the windows, sensible heat that is introduced from outside air through ventilation, heat that is generated from electrical equipment (mostly monitors), heat generated by lights, and sensible heat generated by people.

- Heat sources not taken into account include

  - Interior walls: It is assumed that the temperature differences are small, and hence the heat transferred is negligible.

- This is only a "ball park" figure because there have been many assumptions made. The assumptions have been listed in their appropriate places. Wherever possible, the assumptions made reflect as close as possible to the known construction of the trailer and the types and numbers of equipment, or are worst case assumptions like time of day and position for solar calculations.

- Some specifications that are known about the trailer are

  - The size of the control room is 24 ft 4 in. × 13 ft 4 in. The size of the geophysics room is 9 ft, 4 in. × 13 ft, 4 in.
  - The trailer has a composition roof with R-14 insulation in the ceiling[a]
  - The roof has a nominal 3/12 pitch
  - It has R-11 walls, and 2 in. × 6 in. exterior walls
  - It has R-7 insulation in the floors.

- The method of predicting the cooling load from the roof, walls, ventilation, and heat gains through the windows is a Cooling Load Temperature Difference (CLTD) method presented in the 1981 ASHRAE Fundamentals Handbook (26.7). This method uses Sol-Air temperatures. The Sol-Air temperature is that temperature of the outdoor air which, in the absence of all radiation exchanges would give the same rate of heat entry

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a. DOE Architectural Engineering Standards, Appendix K, Sect. 3.2 states that insulation in the roof should be R-19; insulation in the walls should be R-11; and insulation in the floor should be R-19. It was decided that since the existing insulation in the trailer has lower R values, the worst case cooling load would occur if this existing insulation is not changed.

into the surface as would exist with the actual combination of solar and convective heat exchange with the outside surface. The cooling load from any equipment is based on its total estimated power consumption. Methods for the lights and people are from Chapter 26 of the 1981 ASHRAE Fundamentals Handbook.

I-1.1 Roof

$q = U \times A \times CLTD.$

Find U:

Table 23.4K[b], Construction 2 => U_{av} = 0.141 Btu/(hr ft^2 F).

This is for a pitched roof that comes closest to the construction and conditions of the trailer, but it does not take into account for the R-14 insulation in the ceiling. Table 23.5A was used with a starting U of 0.14 and an R addition of 14 to get a new U value of U = 0.05 Btu/(hr ft^2 F).

Find A:

Because of the pitched roof, the length to the middle is

$L = \text{sqrt}\ [(80\ \text{in.})^2 + [(80\ \text{in.})(3/12)]^2] = 82.5\ \text{in.}$
The total length is 2L = 165 in. = 13.75 ft
$A = (13.75\ \text{ft})(24.33\ \text{ft} + 9.33\ \text{ft}) = 476.66\ \text{ft}^2.$

Find the Max CLTD:

Table 26.5A - need to find a roof with similar mass and heat capacity (Btu/ft^2 F). The closest roof for heat capacity and construction is the #1 roof with a suspended ceiling.

This roof has a Max CLTD of

Max CLTD = 78 Table 26.5A, Roof No. 1.

The next step in the method is to apply correction factors to the CLTD to account for the latitude, the time of year, the color of the surface, and the variations in outdoor and indoor temperatures between this design and the handbook's standard temperatures.

$CLTD_{corr} = [(CLTD + LM) \times K + (78 - T_R) + (T_O - 85)] \times f$
LM highest in June, LM = 2 (worst case)
K = 1.0 (It is not known what color the surface is so use the worst case)
Want to maintain room at 72 ± 2 F,
(1991 ASHRAE Handbook Chapter 17 on computer rooms)

b. All tables referenced are in the ASHRAE 1981 Fundamentals Handbook.

Summer conditions call for an outside temp. of T_O = 93°F in this location (DOE Architectural Engineering Standards 1550, Section 3.1)

$(78 - T_R) = 6$ F

$(T_O - 85) = 8$ F

f = 1.0 for no attic fans

q = (0.05)(476.66)[(78+2)(1.0) + 6 + 8](1.0) = 2240 Btu/hr

q = 656.6 W.

I-1.2 Exterior Walls

$q = U \times A \times CLTD.$

Find U:

Table 23.4A gives U values for frame walls. Construction 2 is for walls with R-11 insulation; however, this table uses a 2 in. × 4 in. stud rather than a 2 in. × 6 in. which exists in the trailer. The R value for a 2 × 4 is 4.35. From Table 23.3A the R value for a 2 × 6 is 7.14. With this change, the total thermal resistance at the framing is

R = 10.57.

The thermal resistance between the frames does not change. The total U value for both is then:

U = 0.8(1/14.43) + 0.2(1/10.57) = 0.074.

Find A:

Side wall height = 7.5 ft
Width = 24.33 ft for control room
= 9.33 ft for geophysics room
= 13.75 ft for the end of the trailer
A = (24.33 + 9.33 ft)(7.5 ft) = 252.5 ft^2 for the sides
A = (13.75 ft)(7.5 ft) = 103.125 ft^2 for the end.

Find Max CLTD:

From Table 26.6: Frame walls are group G walls
From Table 26.7A: The Max CLTD (worst case) for a group G wall is at 5:00 p.m. with one wall facing east and one wall facing west:
West: CLTD = 72
East: CLTD = 27
North: CLTD = 25.

The next step is to apply the correction factors:

$CLTD_{corr} = [(CLTD + LM) \times K + (78 - T_R) + (T_O - 85)]$
As for the roof, LM is highest in June => LM = 2 (Table 26.9A)

K = 1.0 (It is not known what the color of the surface is, so use the worst case)
For the same reasons as the roof, T_O = 93 F and T_R = 72 F.

For the west facing wall,

$$CLTD_{corr} = (72+2)(1.0) + (78\text{-}72) + (93\text{-}85) = 88.$$

For the east facing wall,

$$CLTD_{corr} = (27+2)(1.0) + (78\text{-}72) + (93\text{-}85) = 43.$$

For the end facing north,

$$CLTD_{corr} = (25+2)(1.0) + (78\text{-}72) + (93\text{-}85) = 41.$$

For the west facing wall,

q = (0.074)(252.5)(88) = 1644 Btu/hr.
q = 482 W

For the east facing wall,

q = (0.074)(252.5)(43) = 803.5 Btu/hr
q = 235.5 W.

For the north facing wall,

q = (0.074)(103.125)(41.) = 313 Btu/hr
q = 91.7 W.

Total = 482 W + 235.5 W + 91.7 W = 809.2 W.

I-1.3 Conduction Through Glass Windows

$q = U \times A \times CLTD.$

Find U:

Assume that the windows are flat glass, double paned insulating, with 1/4-in. thick glass, and with no shade. The worst loading will be during the summer. Table 23.8A gives: U = 0.61.

Find A:

All windows in the control and geophysics rooms are 46 in. × 58 in.
A = (46 in.)(58 in.) = 2668 in.^{2} = 18.53 ft^2 per window.

Find the Max CLTD:

From Table 26.10, the maximum CLTD is at 3:00 and 4:00 p.m., it is
Max CLTD = 14.

Need to correct the Max CLTD because it is for an indoor temperature of 78°F. To do this, add the difference between 78°F and an indoor temperature of 72°F to the Max CLTD. Max CLTD = 20.

$$q = 4[(0.61)(18.53)(20)] = 904.2 \text{ Btu/hr}$$
$$q = 265 \text{ W}.$$

I-1.4 Solar Gain Through Windows

$$q = A \times SC \times SHGF \times CLF.$$

Find A:

$$A = 18.53 \text{ ft}^2 \text{ per window (see above).}$$

Find SC:

Assume windows are flat insulating glass that is clear and 1/4 in. thick. Also assume that the air on the inside is still, and there is a 7.5 mph wind on the outside. Table 27.28B gives SC = 0.81.

Find the Solar Heat Gain Factor (SHGF):

Although the solar heat gain factor is higher in the winter, the maximum cooling loads being calculated are for the summer. June has been the month previously used for the cooling load temperature difference calculations, so June will be used for this.

For June and for windows facing east or west, at 44 degree N latitude, Table 26.11A gives SHGF = 215. For a window facing north, this table gives SHGF = 47.

Find the Cooling Load Factor (CLF):

Assume there will be interior shading, then Table 26.14 is good for all types of room construction. The worst case is for windows facing east and west at 4:00 p.m. with the wall with two windows facing west, and the end of the trailer facing north. This gives

West facing windows: CLF = 0.82
East facing windows: CLF = 0.17
North facing window: CLF = 0.75.

For west facing windows,

$$q = 2[(18.53)(0.81)(215)(0.82)] = 5292 \text{ Btu/hr}$$
$$q = 1551 \text{ W}.$$

For east facing windows,

$$q = (18.53)(0.81)(215)(0.17) = 548.6 \text{ Btu/hr}$$
$$q = 160.8 \text{ W}.$$

For north facing window,

$$q = (18.53)(0.81)(47)(0.75) = 529 \text{ BTU/hr}$$
$$q = 155 \text{ W.}$$

Total: $q = 1867$ W.

I-1.5 Partitions

Assume heat gain from inside walls to be negligible because the temperature differences are small.

I-1.6 Floor

$$q = U \times A \times TD.$$

Assume the temperature under the trailer is halfway between the inside and outside temperatures:

$$T = 0.5(93 + 72) = 82.5 \text{ F.}$$

Table 23.4G gives U values for frame ceilings and floors, Construction 2 is for floors with R-19 insulation; however, the trailer as it exists has R-7 insulation in the floor. With this change, the total thermal resistance between the framing is

$$R = 8.69.$$

The thermal resistance at the frames does not change. The total U value for both is then

$$U = 0.9(1/8.69) + 0.1(1/10.14) = .1134$$

$$A = (24.33 \text{ ft})(13.33 \text{ ft}) = 324.4 \text{ ft}^2$$

$$TD = 82.5 - 72 = 10.5 \text{ F}$$

$$q = (.1134)(324.4)(10.5) = 386.3 \text{ Btu/hr} = 113 \text{ W.}$$

I-1.7 Internal lights

Assume that the total lighting will not be too high in order to avoid creating glare on the monitors, and assume it is (or is equivalent to) 350 W.

Assume ordinary furniture, no carpet, medium to high ventilation rate, and recessed, nonvented light fixtures are representative of the control room. => Table 26.15 gives "a" coefficient = 0.55.

Assume a wood floor covered only with floor tile is representative of the control room. => Table 26.16 gives "b" classification = A.

Assume lights are on for 10 hours/day. After the lights have been on for 10 hours, the cooling load factor is 0.94 (Table 26.17B).

$$q = \text{Input} \times \text{CLF}$$
$$= (350\ \text{W})(.94)$$
$$q = 329\ \text{W}\,.$$

I-1.8 People

Assume that there will be seven people working in the control room and geophysics room, and that these people work for 8 hours straight.

Table 26.18 says that for standing, light work, or walking slowly the total adjusted heat is 185 W per person (90 W sensible heat, 95 W latent heat).

$q_{sensible}$ = No. of people × sensible heat gain × CLF.

The highest CLF is after the people have been in the rooms for 8 hours, Table 26.19 gives CLF = 0.84.

$q_{sensible} = (7)(90)(0.84) = 529.2$ W.

I-1.9 Ventilation and Infiltration Air

Sensible heat gain $q_s = 1.1 \times \text{CFM} \times \text{delta T}$.

Assume 20 cfm per person ventilation (ASHRAE Std. 62-89) and seven people in the room: CFM = (7)(20) = 140 cfm.

$q_s = (1.1)(140)(93\text{-}72) = 3234$ Btu/hr
$q_s = 984$ W.

I-1.10 Equipment

The equipment (monitors) required for the gantry crane is known:

12 small 4 in. × 4 in. monitors => Assume 40 W each => 480 W
5 large 14 in. monitors => Assume 85 W each => 425 W
4 CRT computer type monitors => 85 W each for 14 in. screens => 340 W
Total cooling load for gantry crane equipment => 1245 W.

Assume that the following workstations will each require the same types and numbers of equipment:

Conveyance
Excavator
Supervisor.

Total Equipment Cooling Load = (4)(1245 W) = 4980 W.

I-1.11 Approximate Total Cooling Load

Roof: 656.6 W
Exterior Walls: 809.2 W
Conduction Through Glass: 265 W
Solar Gain Through Glass: 1867 W
Floor: 113 W
Internal Lights: 329 W
People: 529.2 W
Ventilation: 948 W
Equipment: 4980 W
TOTAL: 10,497 W (35,817 Btu/hr)

For a Safety Factor of 1.5, the total cooling load becomes 15,746 W or 53,726 Btu/hr (about a 4.5 ton unit).

I-2. CONFERENCE ROOM

- The cooling load that has been approximated takes into account the heat conducted through the exterior walls and roof of the conference room due to solar radiation and convective heat exchange with the outside air, heat conducted through the windows, solar gain through the windows, sensible heat that is introduced from outside air through ventilation, heat that is generated from electrical and visual equipment, heat generated by lights, and sensible heat generated by people.

- Heat sources not taken into account include

    - Interior walls: It is assumed that the temperature differences between rooms are small, and hence the heat transferred is negligible.

- This is only a "ball park" figure because there have been many assumptions made. The assumptions have been listed in their appropriate places. Wherever possible the assumptions made reflect as close as possible to the known construction of the trailer, or are worst case assumptions like time of day and position for solar calculations.

- Some specifications that are known about the trailer are

    - The size of the room is approximately 13 ft × 13 ft 4 in.

- It has a composition roof with R-14 insulation in the ceiling[c]
- The roof has a nominal 3/12 pitch
- It has R-11 in the walls, and 2 in × 6 in. exterior walls
- It has R-7 insulation in the floors.

- Assumptions that were made are listed in their appropriate places.

- The method of predicting the cooling load from the roof, walls, ventilation, and heat gains through the windows is a CLTD method presented in the 1981 ASHRAE Fundamentals Handbook (26.7). This method uses Sol-Air temperatures. The Sol-Air temperature is that temperature of the outdoor air which, in the absence of all radiation exchanges, would give the same rate of heat entry into the surface as would exist with the actual combination of solar and convective heat exchange with the outside surface. The cooling load from any equipment is based on its total estimated power consumption. Methods for the lights and people were also taken from Chapter 26 of the 1981 ASHRAE Fundamentals Handbook.

I-2.1 Roof

$q = U \times A \times CLTD.$

Find U:

Table 23.4K[d], Construction 2 => U_{av} = 0.141 Btu/(hr ft^2 F). This is for a pitched roof that comes closest to the construction and conditions of the trailer, but it does not take into account for the R-14 insulation in the ceiling. Table 23.5A was used with a starting U of .14 and an R addition of 14 to get a new U value of U = 0.05 Btu/(hr ft^2 F).

Find A:

Because of the pitched roof, the length to the middle is

$L = \text{sqrt}\ [(80\ \text{in.})^2 + [(80\ \text{in.})(3/12)]^2] = 82.5\ \text{in.}$
The total length is 2L = 165 in. = 13.75 ft
$A = (13.75\ \text{ft})(13\ \text{ft}) = 178.7\ \text{ft}^2.$

Find the Max CLTD:

c. DOE Architectural Standards, Appendix K, Section 3.2 states that insulation in the roof should be R-19; insulation in the walls should be R-11; and insulation in the floor should be R-19. It was decided that since the existing insulation in the trailer has lower R values, the worst case cooling load would occur if this insulation is not changed.

d. DOE Architectural Standards, Appendix K, Section 3.2 states that insulation in the roof should be R-19; insulation in the walls should be R-11; and insulation in the floor should be R-19. It was decided that since the existing insulation in the trailer has lower R values, the worst case cooling load would occur if this insulation is not changed.

Table 26.5A - need to find a roof with similar mass and heat capacity (Btu/ft^2 F). The closest roof for heat capacity and construction is the #1 roof with a suspended ceiling.

This roof has a Max CLTD of

Max CLTD = 78 Table 26.5A, Roof No. 1.

The next step in the method is to apply correction factors that compensate for considerations such as the latitude (L), time of year (M), color of the roof (K), and variations in indoor (T_R) and outdoor (T_O) temperatures from the standard temperatures.

$CLTD_{corr} = [(CLTD + LM) \times K + (78\text{-}T_R) + (T_O - 85)] \times f$

LM highest in June, LM = 2 (worst case)

K = 1.0 (it is not known what the color will be, so use the worst case)

Want to maintain room at 72 ± 2°F, (1991 ASHRAE Handbook Chapter 17 on computer rooms). Summer design conditions call for an outside temperature of T_O = 93°F in this location. (DOE Architectural Engineering Standards 1550 Sect. 3.1)

$(78 - T_R) = 6°F$

$(T_O - 85) = 8°F$

f = 1.0 for no attic fans

$q = (0.05)(178.7)[(78+2)(1.0) + 6 + 8](1.0) = 840$ Btu/hr

q = 240 W.

I-2.2 Exterior Walls

$q = U \times A \times CLTD.$

Find U:

Table 23.4A gives U values for frame walls, Construction 2 is for walls with R-11 insulation; however, this table uses a 2 in × 4 in. stud rather than a 2 in. × 6 in. stud, which exists in the trailer.

The R value for a 2 × 4 is 4.35.

From Table 23.3A the R value for a 2 × 6 is 7.14.

With this change, the total thermal resistance at the framing is R=10.57.

The thermal resistance between the frames does not change.

The total U value for both is then:

$U = 0.8(1/14.43) + 0.2(1/10.57) = 0.074.$

Find A:

Side wall height = 7.5 ft

Width = 13 ft

A = (13 ft)(7.5 ft) = 97.5 ft^2 for each wall.

Find The Max CLTD:

From Table 26.6: Frame walls are group G walls.

From Table 26.7A: The Max CLTD (worst case) for a group G wall is at 5:00 p.m. with one wall facing east and one wall facing west:
West: CLTD = 72
East: CLTD = 27.

As in the roof calculations, the next step is to apply correction factors:

$CLTD_{corr}$ = [(CLTD +LM) × K + (78-T_R) + (T_O - 85)]
As for the roof, LM is highest in June => LM = 2 (Table 26.9A)
K = 1.0 (it is not known what the color is so use the worst case)
For the same reasons as the roof, T_O = 93 F and T_R = 72 F

For the west facing wall,

$CLTD_{corr}$ = (72+2)(1.0) + (78-72) + (93-85) = 88.

For the east facing wall,

$CLTD_{corr}$ = (27+2)(1.0) + (78-72) + (93-85) = 43.

For the west facing wall,

q = (0.074)(97.5)(88) = 635 Btu/hr
q = 186 W.

For the east facing wall,

q = (0.074)(97.5)(32.85) = 310 Btu/hr
q = 91 W.

I-2.3 Conduction Through Glass Windows

q = U × A × CLTD.

Find U:

Assume that the windows are flat glass, double paned insulating, with 1/4 in. thick glass, and with no shade.
The worst loading will be during the summer.
Table 23.8A gives U = 0.61.

Find A:

All windows in the conference room are 30 in. × 58 in.
A = (30 in.)(58 in.) = 1740 $in.^2$ = 12.08 ft^2 per window.

Find the Max CLTD:

From Table 26.10, the maximum CLTD is at 3:00 and 4:00 p.m. and is
Max CLTD = 14.

Need to correct the Max CLTD because it is for an indoor temperature of 78°F

To do this, add the difference between 78°F and an indoor temperature of 72°F to the Max CLTD.
Max CLTD = 20
q = 3[(0.61)(12.08)(20)] = 442 Btu/hr
q = 129.6 W.

I-2.4 Solar Gain Through Windows

$q = A \times SC \times SHGF \times CLF.$

Find A:

A = 12.08 ft^2 per window (see above).

Find SC:

Assume windows are flat insulating glass that is clear and 1/4 in. thick. Also, because this is what the table lists, assume that the air on the inside is still, and there is a 7.5 mph wind on the outside. Table 27.28B gives SC = 0.81.

Find the Solar Heat Gain Factor (SHGF):

Although the solar heat gain factor is higher in the winter, the maximum cooling loads that are being calculated are for the summer. June has been the month previously used for the cooling load temperature difference calculations, so June will be used for this.

For June and for windows facing east or west, at 44 degree N latitude, Table 26.11A gives: SHGF = 215.

Find the Cooling Load Factor (CLF):

Assume a light constructed building.

The worst case for windows facing east and west is at 6:00 p.m. with the wall with two windows facing west. This gives west facing windows: CLF = 0.61 and east facing windows: CLF = 0.19.

For west facing windows,

q = 2[(12.08)(0.81)(215)(0.61)] = 2566.6 Btu/hr
q = 752 W.

For east facing windows,

$$q = (12.08)(0.81)(215)(0.19) = 399.7 \text{ Btu/hr}$$
$$q = 117.1 \text{ W.}$$

Total: $q = 869.1$ W.

I-2.5 Partitions

Assume heat gain from inside wall to be negligible because the temperature differences are small.

I-2.6 Floor

$$q = U \times A \times TD.$$

Assume the temperature under the trailer is halfway between the inside and outside temperatures. $T = 0.5(93 + 72) = 82.5$ F.

Table 23.4G gives U values for frame ceilings and floors. Construction 2 is for floors with R-19 insulation; however, the trailer as it exists, has R-7 insulation. With this change, the total thermal resistance between the framing is R = 8.69. The thermal resistance at the frames does not change. The total U value for both is then:

$$U = 0.9(1/8.69) + 0.1(1/10.14) = 0.1134$$

$$A = (13 \text{ ft})(13 \text{ ft } 4 \text{ in.}) = 173.3 \text{ ft}^2$$

$$TD = 82.5 - 72 = 10.5 \text{ F}$$

$$q = (.1134)(173.3)(10.5) = 206.15 \text{ Btu/hr}$$
$$q = 60.4 \text{ W.}$$

I-2.7 Internal lights

Assume that the total lighting is (or is equivalent to) 300 W. This could be three 100 W light bulbs for instance.

Assume ordinary furniture, no carpet, medium to high ventilation rate, and recessed, nonvented light fixtures are representative of the conference room. => Table 26.15 gives "a" coefficient = 0.55.

Assume a wood floor covered only with floor tile is representative of the conference room => Table 26.16 gives "b" classification = A.

Assume light is on for 10 hours/day (or at a time maximum).

After the light has been on for 10 hours, the cooling load factor is 0.94 (Table 26.17B)

q = Input × CLF
= (300 W)(.94)
q = 282 W.

I-2.8 People

A room this size can hold about 12 people, for worst case conditions assume that 15 people are in the room.

Because the major portion of the cooling load in this room comes from people, it is important to include both the sensible and latent heat.

Table 26.18 says that for standing, light work, or walking slowly the total adjusted heat gain (HG) is 185 W per person (90 W sensible heat, 95 W latent heat).

$q_{sensible}$ = No. of people × Sensible heat gain × CLF.

Assume that the worst case will be for the conference room to be filled for 4 hours. Table 26.19 gives the highest cooling load factor (CLF) at the point when the people have been in the room for 4 hours, this is:

CLF = 0.71
$q_{sensible} = (15)(90)(0.71) = 958.5$ W

q_{latent} = No. of people × Lat. HG
$q_{latent} = (15)(95) = 1425$ W
The total cooling load from people is 958.5W + 1425W = 2383.5 W.

I-2.9 Ventilation and Infiltration Air

Sensible heat gain $q_s = 1.1 \times \text{CFM} \times \text{delta T}$.

Assume 20 cfm per person ventilation and 15 people in the room
CFM = (15)(20) = 300 cfm.

$q_s = (1.1)(300)(93\text{-}72) = 6930$ Btu/hr
$q_s = 2030$ W.

I-2.10 Equipment

There will probably be some audiovisual equipment in the room, but it is not known at this time what that will consist of so assume then equipment in the room creates 200 W of cooling load. (This is about the equivalent of 3 additional people.)

I-2.11 Approximate Total Cooling Load

Roof: 240 W
Exterior Walls: 277 W
Conduction Through Glass: 129.6 W
Solar Gain Through Glass: 869.1 W
Floor: 60.4 W
Internal Lights: 282 W
People: 2383.5 W
Ventilation: 2030 W
Equipment: 200 W
TOTAL: 6.41 kW (21,875 Btu/hr)

For a Safety Factor of 1.5, the total cooling load becomes 9.62 kW or 32,812 Btu/hr (almost a 3 ton unit).

Note: The bathroom is in the same zone and will probably be cooled by the same unit, but the cooling load calculations are not included in this first pass conceptual estimate. These calculations would take into account everything above except the equipment and the people (since people in the bathroom would have already been taken into account in the conference room).

I-3. EQUIPMENT ROOM

- The cooling load that has been approximated takes into account the heat conducted through the exterior wall, ceiling, and floor of the equipment room, sensible heat that is introduced from outside air through ventilation, heat that is generated from electrical equipment, heat generated by lights, and sensible heat generated by people.

- Heat sources not taken into account include:

    - Conduction through windows: The best design would be to have no windows in this room
    - Solar radiation through windows: Same as above
    - Interior walls: It is assumed that the temperature differences are small, and hence the heat transferred is negligible.

- This is only a "ball park" figure because there are still many unknowns. For instance, the numbers and type of electrical equipment: It is a fairly good assumption that the gantry crane will require 1 workstation and 1 PC. It was assumed that the entire system will require 6 workstations and 2 PCs.

- Some specifications that are known about the trailer are:

    - The size of the room is approximately 5 ft × 8 ft

- It has a composition roof with R-14 insulation in the ceiling[e]
- The roof has a nominal 3/12 pitch
- It has R-11 insulation in the walls and 2 in. × 6-in. exterior walls
- It has R-7 insulation in the floors.

- Assumptions that were made are listed in their appropriate places.

- The method of predicting the cooling load from the roof, walls, floor, and ventilation is a Cooling Load Temperature Difference (CLTD) method presented in the 1981 ASHRAE Fundamentals Handbook (26.7). This method uses Sol-Air temperatures. The Sol-Air temperature is that temperature of the outdoor air which, in the absence of all radiation exchanges would give the same rate of heat entry into the surface as would exist with the actual combination of solar and convective heat exchange with the outside surface. The cooling loads from the equipment are based on their total estimated power consumption. Methods for the lights and people are from Chapter 26 of the 1981 ASHRAE Fundamentals Handbook.

I-3.1 Roof

$q = U \times A \times CLTD$

Find U:

Table 23.4k[f], Construction 2 => $U_{av} = 0.141$ Btu/(hr ft^2 F).

This is for a pitched roof that comes closest to the construction and conditions of the trailer, but it does not take into account for the R-14 insulation in the ceiling. Table 23.5A was used with a starting U of 0.14 and an R addition of 14 to get a new U value of U = 0.05 Btu/(hr ft^2 F).

Find A:

Because of the pitched roof the length is

$L = \text{sqrt}\ [(8\ \text{ft})^2 + [(8)(3/12)]^2] = 8.25\ \text{ft}$

$A = (8.25\ \text{ft})(5\ \text{ft}) = 41.2\ \text{ft}^2.$

Find the Max CLTD:

Table 26.5A - need to find a roof with similar mass and heat capacity (Btu/ft^2 F). The closest roof for heat capacity and construction is the #1 roof with a suspended ceiling. The fact that it is

e. DOE Architectural Standards, Appendix K, Section 3.2 states that insulation in the roof should be R-19; insulation in the walls should be R-11; and insulation in the floor should be R-19. It was decided that since the existing insulation in the trailer has lower R values, the worst case cooling load would occur if this insulation is not changed.

f. All tables referenced are in the ASHRAE 1981 Fundamentals Handbook.

not the exact same construction is unimportant as long as the heat capacities are similar. This roof has a Max CLTD of:

Max CLTD = 78 (Table 26.5A, Roof No. 1).

The next step is to apply correction factors to the CLTD that account for the latitude, time of year, color of the surface, and variations in indoor and outdoor temperatures between this design and the handbook's standard values.

$CLTD_{corr} = [(CLTD + LM) \times K + (78 - T_R) + (T_O - 85)] \times f$

LM highest in June, LM = 2 (worst case)

K = 1.0 (We do not know what the color will be, so go with the worst case)

Want to maintain room at 72 ± 2 F,

(1991 ASHRAE Handbook Chapter 17 on computer rooms)

Summer design conditions call for an outside temp. of T_o = 93 Fin this location (DOE Architectural Engineering Standards 1550 Section 3.1)

$(78 - T_R) = 6$ F

$(T_O - 85) = 8$ F

f = 1.0 for no attic fans

$q = (0.05)(41.2)[(78+2)(1.0) + 6 + 8](1.0) = 193$ Btu/hr

$q = 56.75$ W.

I-3.2 Exterior Wall

$q = U \times A \times CLTD.$

Find U:

Table 23.4A gives U values for frame walls. Construction 2 is for walls with R-11 insulation. However, this table uses a 2 in. × 4 in. stud rather than a 2 in. × 6 in. that exists in the trailer. The R value for a 2 × 4 is 4.35.

From Table 23.3A the R value for a 2 × 6 is 7.14.

With this change, the total thermal resistance at the framing is

R = 10.57.

The thermal resistance between the frames does not change.

The total U value for both is then:

$U = 0.8(1/14.43) + 0.2(1/10.57) = 0.074.$

Find A:

Side wall height = 7.5 ft

Width = 5 ft

$A = (5 \text{ ft})(7.5 \text{ ft}) = 37.5 \text{ ft}^2.$

Find the Max CLTD:

From Table 26.6: Frame walls are group G walls

From Table 26.7A: The Max CLTD for a group G wall would be for a wall facing west and at a time of 5 p.m.
This value is => Max CLTD = 72.

The next step is to apply the correction factors to the CLTD:

$CLTD_{corr} = [(CLTD + LM) \times K + (78 - T_R) + (T_O - 85)]$
As for the roof, LM is highest in June => LM = 2 (Table 26.9A).
K = 1.0 (The color of the surface is not known so the worst case has been used)
For the same reasons as the roof, T_o = 93 F and T_R = 72 F
$CLTD_{corr} = (72+2)(1.0) + (78-72) + (93-85) = 88$

q = (0.074)(37.5)(88) = 244.2 Btu/hr
q = 71.55 W.

I-3.3 Floor

q = U × A × TD.

Assume the temperature under the trailer is halfway between the inside and outside temperatures:

T = .5(93+72) = 82.5 F.

Table 23.4G gives U values for frame ceilings and floors. Construction 2 is for walls with R-19 insulation. However, the trailer as it exists, has R-7 insulation in the floor. With this change, the total thermal resistance between the framing is
R=8.69.
The thermal resistance at the frames does not change.
The total U value for both is then:
U = .1134.

$A = 5\ ft \times 8\ ft = 40\ ft^2$

TD = 82.5 F - 72 F = 10.5 F

q = (.1134)(40)(10.5) = 47.6 Btu/ hr
q = 14 W.

I-3.4 Conduction through Glass Windows

Assume no windows in equipment room as this would be the best design.

I-3.5 Solar Gain Through Windows

A = net glass area = 0
q = A × SC × SHGF × CLF = 0.

I-3.6 Partitions

Assume heat gain from inside walls to be negligible because the temperature differences are small.

I-3.7 Internal Lights

Assume that the total lighting is (or is equivalent to) one 100 W light bulb.

Assume ordinary furniture, no carpet, medium to high ventilation rate, and recessed, nonvented light fixtures are representative of the equipment room. => Table 26.15 gives "a" coefficient = 0.55.

Assume a wood floor covered only with floor tile is representative of the equipment room => Table 26.16 gives "b" classification = A.

Assume light is on for 10 hours/day.

After the light has been on for 10 hours, the cooling load factor (CLF) is 0.94 (Table 26.17B).

$$q = \text{Input} \times \text{CLF}$$
$$= (100\text{ W})(.94)$$
$$q = 94\text{ W}.$$

I-3.8 People

Assume 2 people are in the equipment room 25% of an 8 hour shift (2 hrs).

For standing, light work, or walking slowly the total adjusted heat is 185 W per person (90 W sensible, 95 W latent heat).

For a total of 2 hrs in the room, 2 hrs afterward the cooling load factor (CLF) is 0.58 (Table 26.19).

$$q_{sensible} = \text{No. of people} \times \text{Sensible heat gain} \times \text{CLF}$$
$$= (2)(90)(0.58)$$
$$q_{sensible} = 104.4\text{ W}.$$

I-3.9 Ventilation and Infiltration Air

Sensible heat gain $q_s = 1.1 \times \text{CFM} \times \text{delta T}$.

Want to keep inside at 72°F, outside design temperature is 93°F.
Assume 20 cfm ventilation per person (ASHRAE Std. 62-89 for office space) for 2 people in the equipment room.

$q_s = (1.1)(40)(93\text{-}72) = 924$ Btu/hr

$q_s = 270.8$ W.

I-3.10 Equipment

Max heat from PC CPU approximately 480 W.
Assume load form workstation approximately 800-1000 W.
Assume: 6 workstations => 6 kW
2 PC CPUs => 0.96 kW.

I-3.11 Total Cooling Load

Roof: 56.75 W
Exterior Wall: 71.55 W
Internal Lights: 94.0 W
People: 104.4 W
Ventilation: 270.8 W
Equipment: 7 kW
Floor: 14.0 W
TOTAL: 7.4 kW (25,165 Btu/hr or a little over a 2 ton cooling unit)

For a Safety Factor of 1.5, the total cooling load becomes 11.1 kW or 37,740 Btu/hr (a little over a 3 ton unit).

Notes: Typical cooling loads for the UPS will be 4,760 Btu/hr; this will also need to be taken into account if the UPS is to be in the equipment room, or it the UPS is to be cooled by the same cooling system.

If the cooling system is to be located in the equipment room also, then there will probably be some amount of heat that it generates in operating that should be taken into account also.

Appendix J

Floor Loading Calculations

Appendix J

J-1. Floor Loading Calculations

The trailer floor construction consists of two 12-in. I-beams that run the length of the trailer with 2 × 6-in. supports on 16-in. centers, running crosswise on top of the I-beams. The centers of the I-beams are 18 in. from the edge of the trailer.

The Uninterrupted Power Supply (UPS) size is 43.1 in. high x 23.6 in. wide x 35.4 in. long. The UPS weighs 1,056 lb. The UPS will be mounted in the dryer alcove so that its length extends into the alcove.

Using proportional measurements on the trailer (Model 47611)[5] floor plan, the UPS will be mounted directly on top of one of the I-beams. From this, the 1,056 lb. load will be easily supported by the I-beam, and detailed floor loading analysis is not necessary. However, the analysis methods are given below to provide guidance on what calculations are required. This information is intended to aid the reader in calculating floor loading should any of the inputs change (UPS load, etc.).

J-2. SAMPLE ANALYSIS METHOD

From the dimensions and orientation of the UPS, we can see that the UPS will rest on two 2 × 6-in. beams.

We will assume that each beam bears one-half of the load, or 528 lb per beam. Each beam will support this distributed load over 23.6 in. of its overall 13.3 ft length.

The analysis should consider the bending stress, shear stress, crushing load, and the maximum deflection.

J-3. STATICS

The reaction forces at the beam supports can be found using statics. For this configuration, each 2 × 6-in. beam would have the following loads (see Figure 1):

P_L and P_R = point loads representing the weight of the trailer roof and walls at both ends of the beam

W_1 = a distributed load spread over 2 ft from one end representing the UPS

W_2 = a distributed load over the entire length representing the dead load of the carpet, floor boards, etc.

W_3 = a distributed load over the area not covered by the UPS representing the live load of people

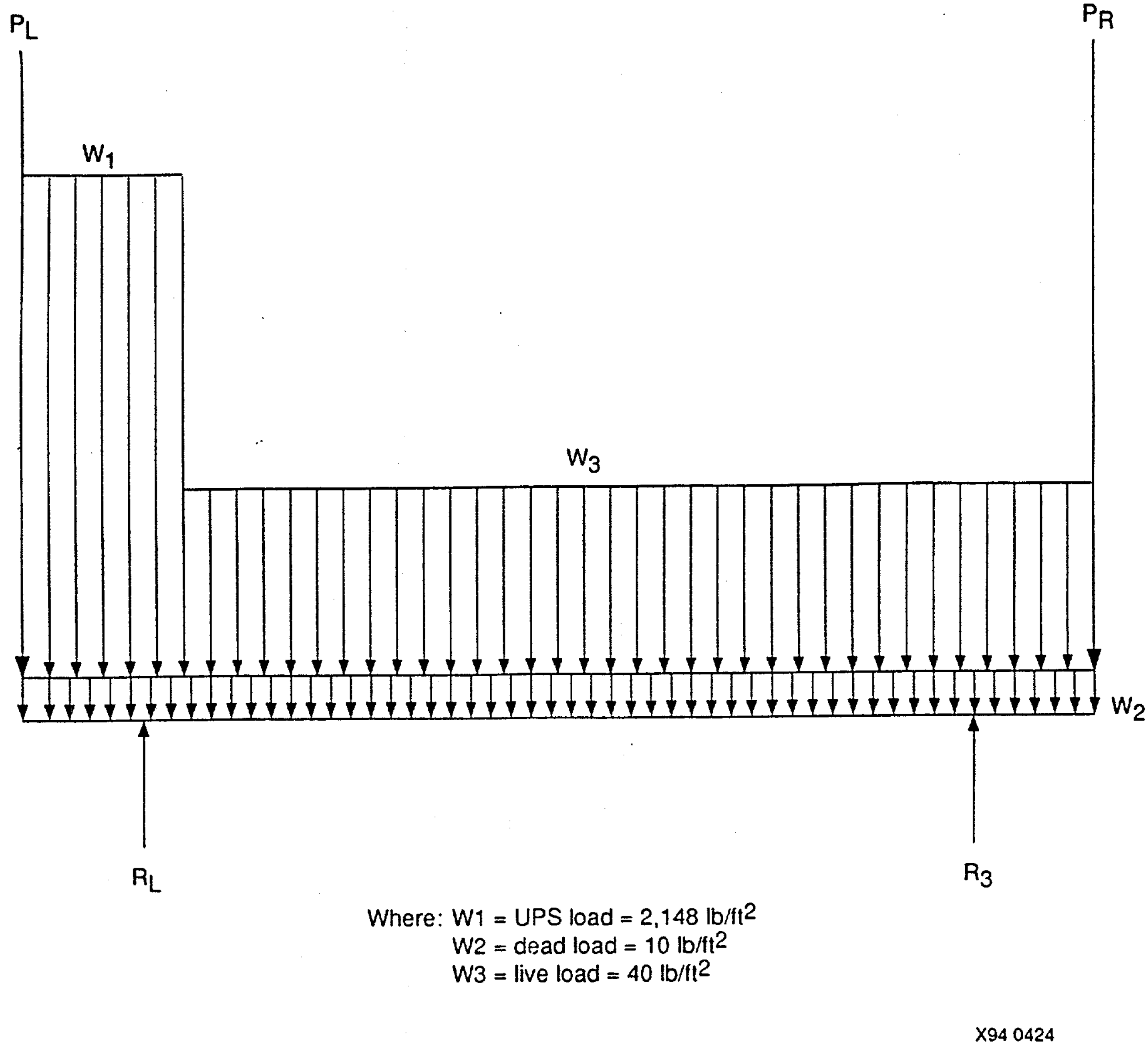


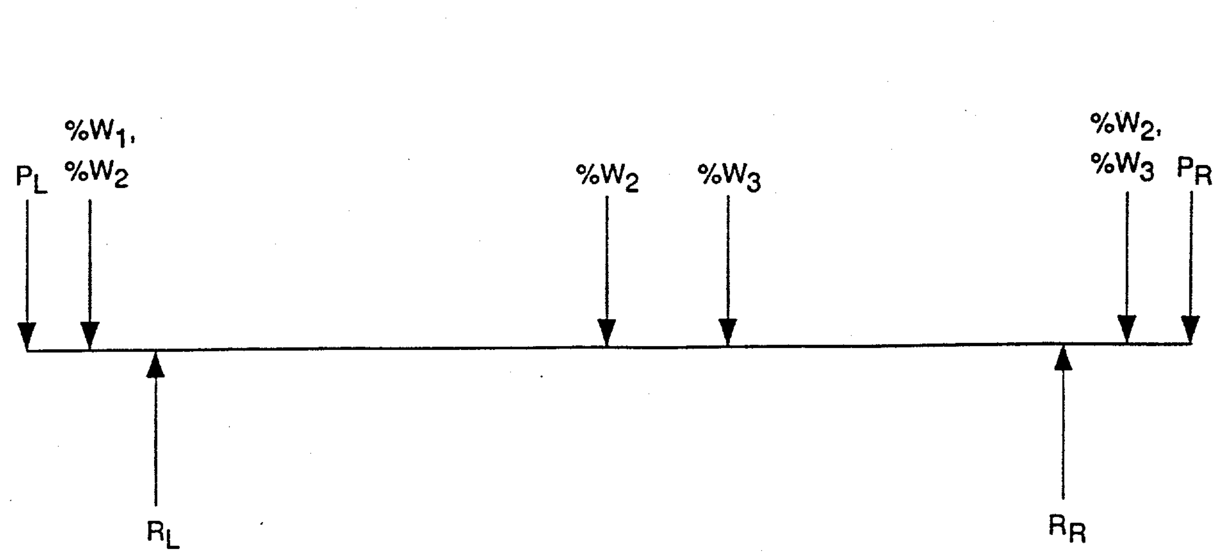
Figure 1. Reaction forces and distributed loads.

R_L and R_R = the two reaction forces would be at the location of the I-beam supports, 1.5 ft from either end.

The dead load and live load values are found in Table 23-A, "Uniform and Concentrated Loads," of the *Uniform Building Code*.

Next, the uniform distributed loads would be modeled as point loads centered proportionately around the support loads (see Figure 2).

By summing forces in the "y" direction and summing moments about one of the reaction forces, we can solve for R_L and R_R.



X94 0-425

Figure 2. Point loads.

J-4. BENDING STRESS

To find the location of the maximum bending stress, the shear and moment equations would be written and the corresponding diagrams drawn. The shear diagram presents the possible locations for the maximum bending stress. The moment diagram depicts the location of the maximum bending stress.

In order to calculate the maximum stress, equations representing the different loading configurations can be combined at the location of the maximum bending stress. For example, the equation for bending stress for

- A uniformly distributed load
- An offset posing load
- Offset distributed load
- Two point loads at the ends.

can all be combined. Each equation is solved at the same "x" of maximum stress that was found using the shear and moment diagrams. Then the results (stress) for each individual case are summed (at the "x" of maximum stess) to find the total maximum stress. This maximum bending stress must be less than the maximum allowable bending stress. The maximum allowable stress can be found in the *Uniform Building Code*. For example, for No. 2 Hem-Fir, 5 in. and wider, single member (2 or less beams), the maximum allowable bending stress is F_B = 950 psi, as found in Table 25-1-1, "Allowable

Unit Stresses - Structural Lumber," *Uniform Building Code*. The calculated maximum bending stress must be less than the maximum allowable bending stress.

J-5. SHEAR STRESS

For maximum shear stress on a simply supported beam:

$F_V = 3V/2A$

where

V = reaction load

A = cross-sectional area of beam (1.5 in. × 5.5 in.).

The shear stress should be less than the maximum shear stress for this type of beam (wood).

For example, the maximum shear (F_V, horizontal shear) for Hem-Fir (North) can be found in Table 25-A-1, "Allowable Unit Stresses - Structural Lumber," of the *Uniform Building Code*. For No. 2 Hem-Fir 5 in. and wider, single member, the maximum allowable shear stress is 75 psi. The calculated maximum shear stress must be less than the maximum allowable shear stress.

J-6. CRUSHING LOAD

The crushing load normally considers the sill that a floor joist rests upon. Since this construction uses an I-beam rather than a sill, we would look at the crushing load on the 2 × 6 in. beams where they rest on the I-beam.

The compressive load is:

F/A

where

F = total load (for this case)

A = area of the 2 × 6 in. resting on the I-beam.

The result should be less than the maximum allowable compression load. The maximum allowable compression load can be found in Table 25-A-1, "Allowable Unit Stresses - Structural Lumber," of the *Uniform Building Code*. For No. 2 Hem-Fir, 5 in. wide, single member, the maximum allowable compression perpendicular to the grain is 370 psi. The calculated maximum compression load must be less than the maximum allowable compression load.

J-7. DEFLECTION

Lastly, the deflection is usually considered for two story buildings and is primarily an appearance issue. The maximum deflection will occur at the location of the maximum moment. The maximum deflection would be found by combining (adding) the maximum deflection at this "x" for each of the loading configurations used in the bending analysis. As a rule of thumb, the deflection of the combined load should be:

$d < l/240$

where

d	=	deflection
l	=	beam length.

Appendix K

Communications

Appendix K

Communciations

Local Area Networking is the successful combination of two distinct technologies: communications and computers. The result has given rise to significant advancements in the data processing industry.

This section provides a guide to the lay person for sorting out the confusing information available about networks. With hundreds of vendors on the market proclaiming their network is best, it is necessary to understand what system fulfills the needs. This section also discusses the recommendations for the HECS communications.

K-1. INTRODUCTION

Over the past decade, electronic data communication has seen many new applications and developments. However, the increasing demand for data processing, interactive equipment, real time high quality video, and expanding networks imposes constraints on current network schemes. Furthermore, different topologies, protocol architecture, and transmission mediums can restrict a network in many situations. To minimize problems associated with network restrictions, it is important for individuals to understand network structure and data packaging.

K-1.1 Network Classification

Networks may be classified into three broad categories:

- Wide area networks (WAN)
- Metropolitan area networks (MAN)
- Local area networks (LAN).

K-1.1.1 Wide Area Networks

WAN covers a national or international area. These networks are usually controlled by regulatory authorities. The most famous WAN was the wide area telephone service. It was implemented in 1961 by AT&T. It provided the ability for users to pay a monthly fee instead of paying on a per call basis. The system is still in use today and is sometimes known as "800" service. Typical parameters for a WAN would be

Distance: > 10,000 km
Bandwidth: 4 KHz-10 MHz
Data Rates: 10^4-10^6 bytes per second (bps).

K-1.1.2 Metropolitan Area Networks

MAN provides city wide coverage. Regulatory bodies own and operate these type of networks. In the United Kingdom, for example, the cable authority was created to monitor the MAN and award cable franchises. Typical parameters for a MAN are

Distance: < 20 km
Bandwidth: 10 KHz-50 MHz
Data Rates: 10^3-10^7 bps

K-1.1.3 Local Area Networks

LAN provides coverage on a private site such as an office building or university. They do not need permission from a regulatory body to be established or operated. The most common types included RS-232, Ethernet, and Token Ring. A few specifications for a LAN are

Distance: <10 km
Bandwidth: 1 Hz-200 MHz
Data rates: 10^6-10^8 bps.

K-1.2 Focus

The primary focus of this report is on LAN because of its flexibility. It can be used as a single data/text network, or *baseband*. Also, it can be used to provide both image and data/text information, or *broadband*. The cable TV industry sometimes uses broadband technology to deliver its service.

K-1.3 History

The LAN was conceived in the 1970s as a method to accomplish distributive processing. It provided the ability to interconnect two identical computers within a point-to-point network. One of the early developments of this technology was the U.S. Department of Defense's long distance private packet-switching network, APRA-NET.

APRANET used a new technology call "packet-switching," which segmented the data on the network into blocks. Each block was given a unique address that allowed the data to route independently throughout the network.

During the same time period, microcomputers became more widely available. Soon the need arose for users to share resources, such as printers, programs, and files. In 1979, Xerox announced the first commercially available LAN, Ethernet. Since then, the Ethernet specifications have become the de facto standard for more than 30 companies involved in the LAN market. Other common network types include RS-232 or Token Ring.

K.2 BACK TO BASICS

K-2.1 Analog and Digital

Information contained in a waveform can be represented in two forms: analog or digital. An analog transmission uses a varying continuous waveform to represent information. A few devices that use analog signals are the television, VCR, or radio transmissions. Analog communication is an effective method to represent data, but digital data are easier to manipulate. A digital signal is composed of two voltage levels that represent binary data. Digital signals are more favorable in many situations because they are inherently less ambiguous than analog signals. Digital systems, which provide two voltage levels, are easier to decipher than analog signals, which provide many voltage levels. Data within a computer are represented by binary symbols and each binary symbol corresponds to an electrical impulse. A binary "1" is a positive voltage and a "0" could be zero volts or a negative voltage (see Figure 1).

K-2.2 Frequency Components

Any electrical signal can be separated into a set of frequency components. Using the mathematical procedure known as Fourier analysis, each component of a waveform can be extracted. A component consists of a periodic sinusoidal waveform, where the frequency is defined as the number of cycles per second, Hertz. In many situations, it is desirable to exclude certain frequencies, because some frequencies are noise. In order to choose only certain frequencies, the signal needs to be filtered. There are four basic types of filters.

- Low pass
- High pass
- Band pass
- Stop band.

A low pass filter blocks all frequencies above a specified point, or cut-off frequency, and passes the rest. A high pass filter is just the opposite. The band pass filter's task is to block all frequencies except for a specific frequency window and a stop band filter is the inverse. Filtering is useful in broadband networks to isolate the desired signal.

K-2.3 Parallel and Serial

To understand how a network packages and sends information, it is necessary to understand the difference between parallel and serial communication. In serial communication, a character is sent sequentially, one bit at a time (see Figure 2). Therefore, a serial interface only requires one data line to send information and one line to receive information. Also a few control and error checking lines are needed.

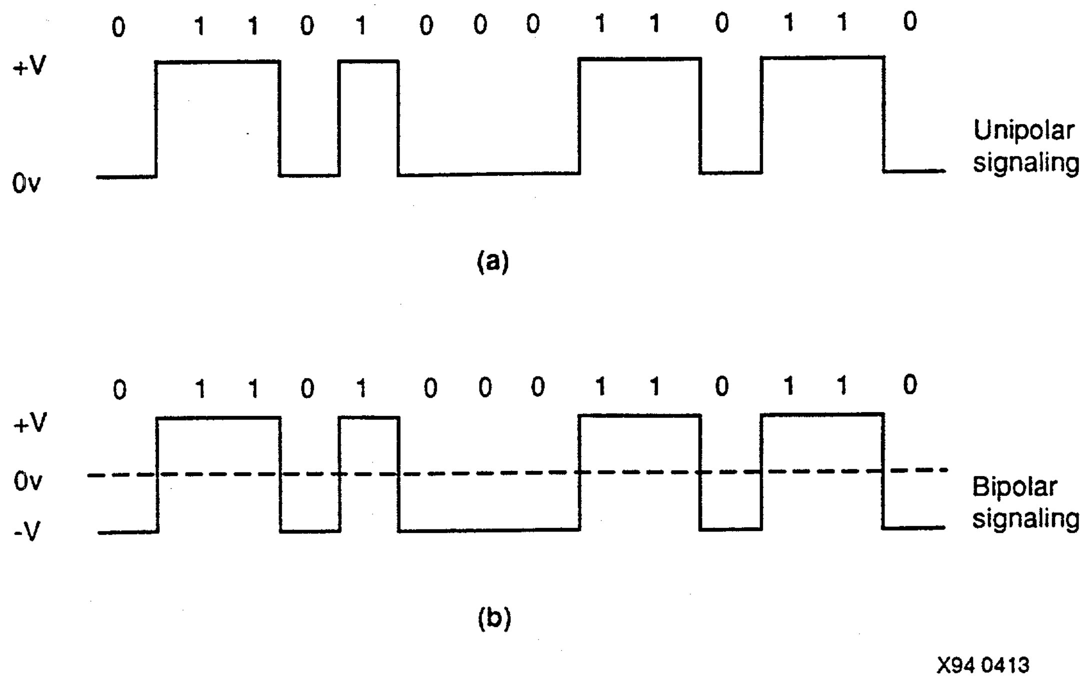


Figure 1. Serial binary data signals.

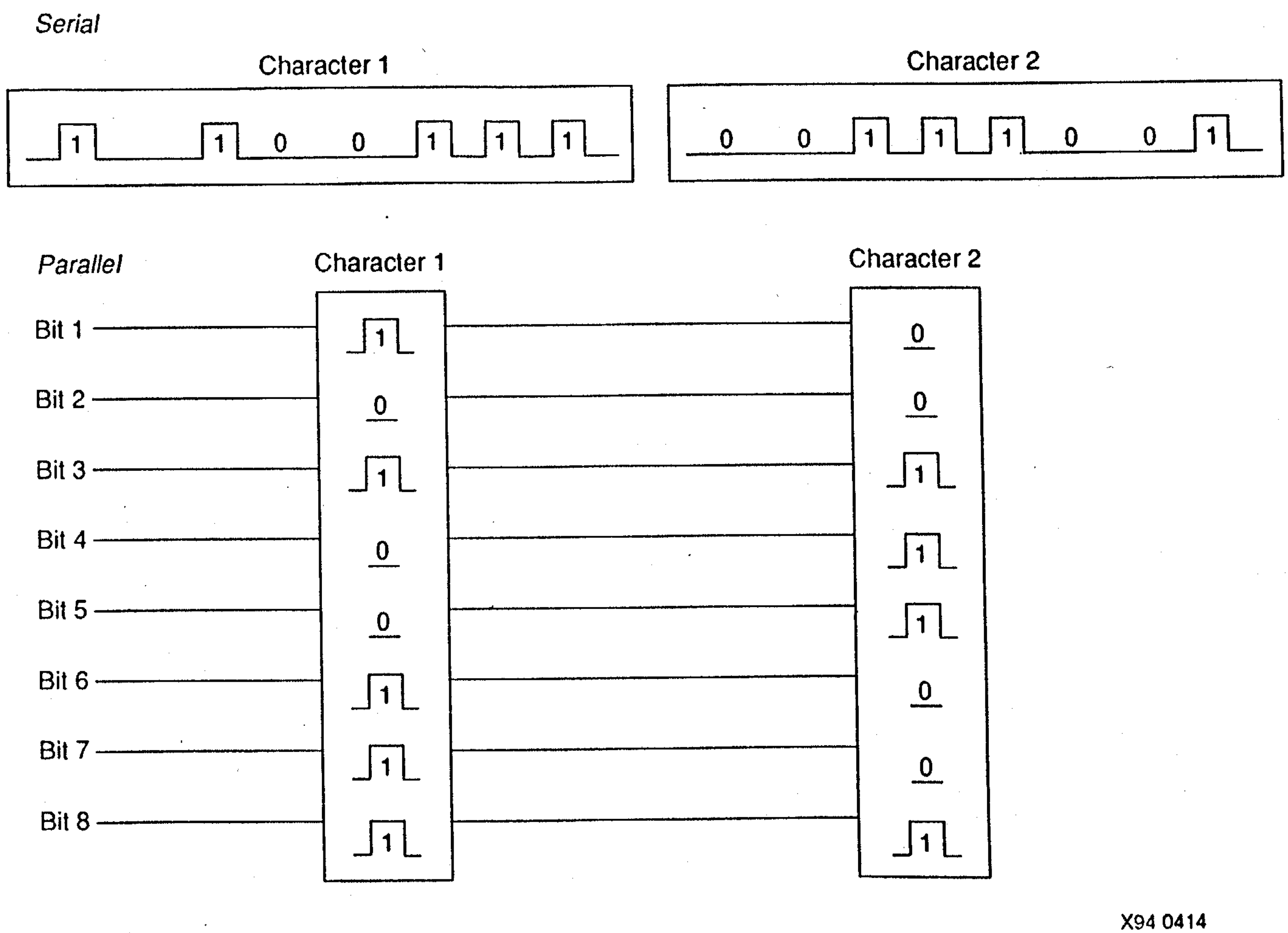


Figure 2. Types of data transmission.

There are several types of serial bus standards. The most popular is the RS-232C standard used by most personal computers. It defines 13 combinations of 20 interface signals for use in data communications. The simplest combination is for a send/receive terminal that requires three of the 20 signals: signal ground, transmitted data, and received data. Most terminals that use RS-232C use the DB-25, 25-pin connector, but it is not defined as part of the standard. The electrical specification for RS-232 buses calls for two equal voltages of opposite polarity ranging from 5 to 25 V. However, since most contemporary logic uses 5 and 0 V, RS-232 does have a serious drawback. Also excessive radio frequency interference (RFI), crosstalk, and limited speed (only 20,000 bps) are problems with the RS-232C serial bus.

In an attempt to resolve these problems associated with RS-232, the Electronic Industries Association introduced RS-422-A and RS-423-A. These buses are essentially the same as RS-232C except they use 5-V positive levels. Still, speed limitations are a problem. To resolve the problem, RS-449 was introduced. It can transmit two mega bits a second, but also uses 10 more signals than RS-232. Although RS-449 outperforms RS-232, RS-232 is still the standard used by most electrical equipment because backward compatibility with existing systems is more important than performance.

In parallel transmitting, an entire character is sent at one time. For this configuration, if a character is eight bits, then the parallel interface will require eight lines to send data. Although parallel communication is faster at transmitting data, most network configurations use serial communications. Serial transmitting is the standard because the transmission medium and the interfaces are less expensive in larger networks. Parallel communicating is almost exclusively used for point-to-point connections. An example would be the connections between computers and peripherals.

K-3. LOCAL AREA NETWORKS

K-3.1 International Standards Organization Model

For LAN technology, it is highly desirable if different machines are able to communicate together. For this to be possible, they must conform to a standard. Currently the National Bureau of Standards is proposing a standard similar to the model developed by the International Standards Organization (ISO).

The ISO model is a seven layer system that illustrates the hierarchy that is necessary for advanced teleprocessing systems. This model is called the Open Systems Interconnection (see Figure 3).

K-3.1.1 Layer 1: Physical

At the lowest level, layer 1, electrical and functional parameters are defined simply to allow a physical link. A few examples of electrical interfaces standards are RS-232, RS-423, or RS-449.

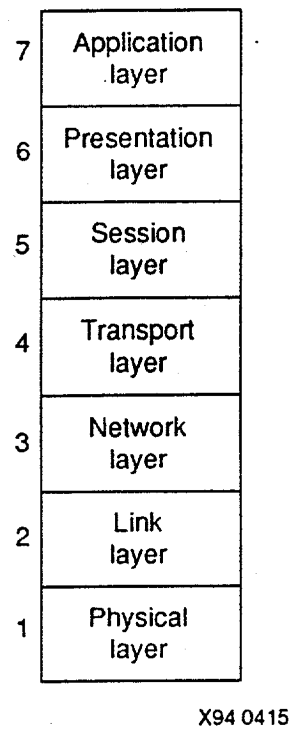


Figure 3. ISO seven layer architectural model.

K-3.1.2 Layer 2: Link Control

Establishing and sending blocks of data over the physical link is the concern of this layer. Due to a degree of unreliability in the physical layer, error checking and correcting functions become necessary. In other words, data may need to be separated into blocks for an error checking scheme or delimiters may be necessary for synchronization purposes.

K-3.1.3 Network

At this level, virtual circuits are required for the exchange of data. Address, control, and acknowledgment fields are added. The standard associated with the network layer is X.25.

K-3.1.4 Transport

The transport layer is concerned with establishing a transport service suited to the needs of the equipment. The functions include integrity controls, prevention of loss, or double processing and flow control.

K-3.1.5 Session

This layer maintains a dialog session between two terminals. Its protocols regulate what users transmit, for how long, and in what order.

K-3.1.6 Presentation

This layer is concerned with transforming data into an acceptable form for processing. Data encryption and decryption, along with code conversion are also tasks of the presentation layer.

K-3.1.7 Application

The last layer is concerned with higher-level functions such as defining the nature of the task to be performed. It provides the user with programs and the actual data to manipulate.

The philosophy of the seven layer system is that each layer is independent of one another. In all actuality, the data and operations are passed down through the layers until they are exchanged in the physical level.

K-3.2 Hardware

There are a few main hardware components that are an integral part of every network.

K-3.2.1 Transceivers

The transceiver is the most common network component. The mechanism allows the signals to transfer from one cable medium to another. They are most commonly used to run from a thick coaxial spine to individual systems (see Figure 4A).

K-3.2.2 Repeaters

The function of a repeater is to repeat an incoming signal to strengthen the signal that is weakened along its transmission distance. It is usually placed between two segments of the same network. A repeater can also be used to repeat signals to many different segments. This would be a multiport repeater. The rules restricting the number of repeaters between nodes vary among manufacturers. It is usually two or four. Too many repeaters results in timing problems throughout the network (see Figure 4B).

K-3.2.3 Bridges

Bridges are similar to repeaters. The difference is that a bridge passes information that is relevant to the nodes to which it is connected. Also, bridges only connect segments using the same protocol, for example, one Ethernet segment with another ethernet segment. The advantage of using a bridge is that it can relieve an overloaded network. If a group of nodes produces heavy traffic and those nodes are mostly communicating with themselves, then it might be best to install a bridge to separate them from the rest of the network (see Figure 4C).

K-3.3.4 Routers

A router is exactly the same as a bridge, expect a router has the added feature of filtering. Under certain circumstances, it may be desirable to send only a specific type of data to a node. A router can perform this task (see Figure 4D).

K-3.3.5 Gateway

The purpose of a gateway is to connect dissimilar types of networks. For instance, a gateway could connect a broadband network to an Ethernet. The gateway will translate from one protocol to another and also handles differences in data formats, speed, and signal levels (see Figure 14E).

K-3.3 Broadband

The baseband concept is relatively simple, send one stream of data on a network to a specified address. However, the broadband concept is a little more complicated.

A broadband network can carry many different signals simultaneously on the same wire. To accomplish this task, the signals must be "broadcast" at different frequencies and sent along the same wire. A typical coaxial cable has a frequency range of 50 to 550 MHz. This means that all of the signals on a broadband network can be "stacked" on top of each other up to 550 MHz. This technique is called frequency multiplexing.

Frequency multiplexing consists of a multiplexer and a demultiplexer, also known as a modulator and demodulator. A multiplexer combines the network signals together. It is usually located at the beginning of the broadband network.

A demultiplexer is a device that is located at the end of a broadband network and it separates the signals. Also, it can be used to route signals throughout a complex. Some systems do not use

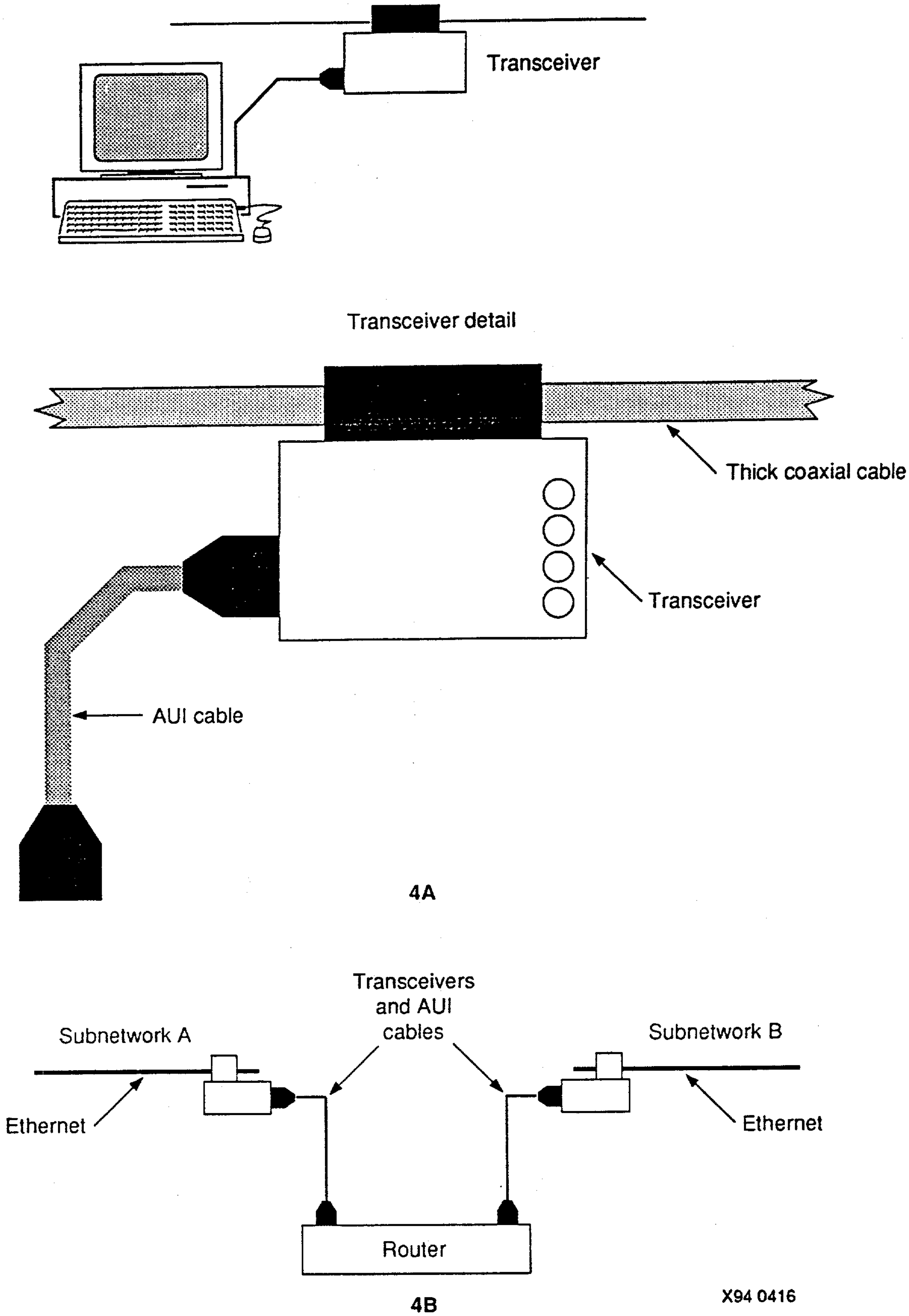


Figure 4A–B. Transceiver and router.

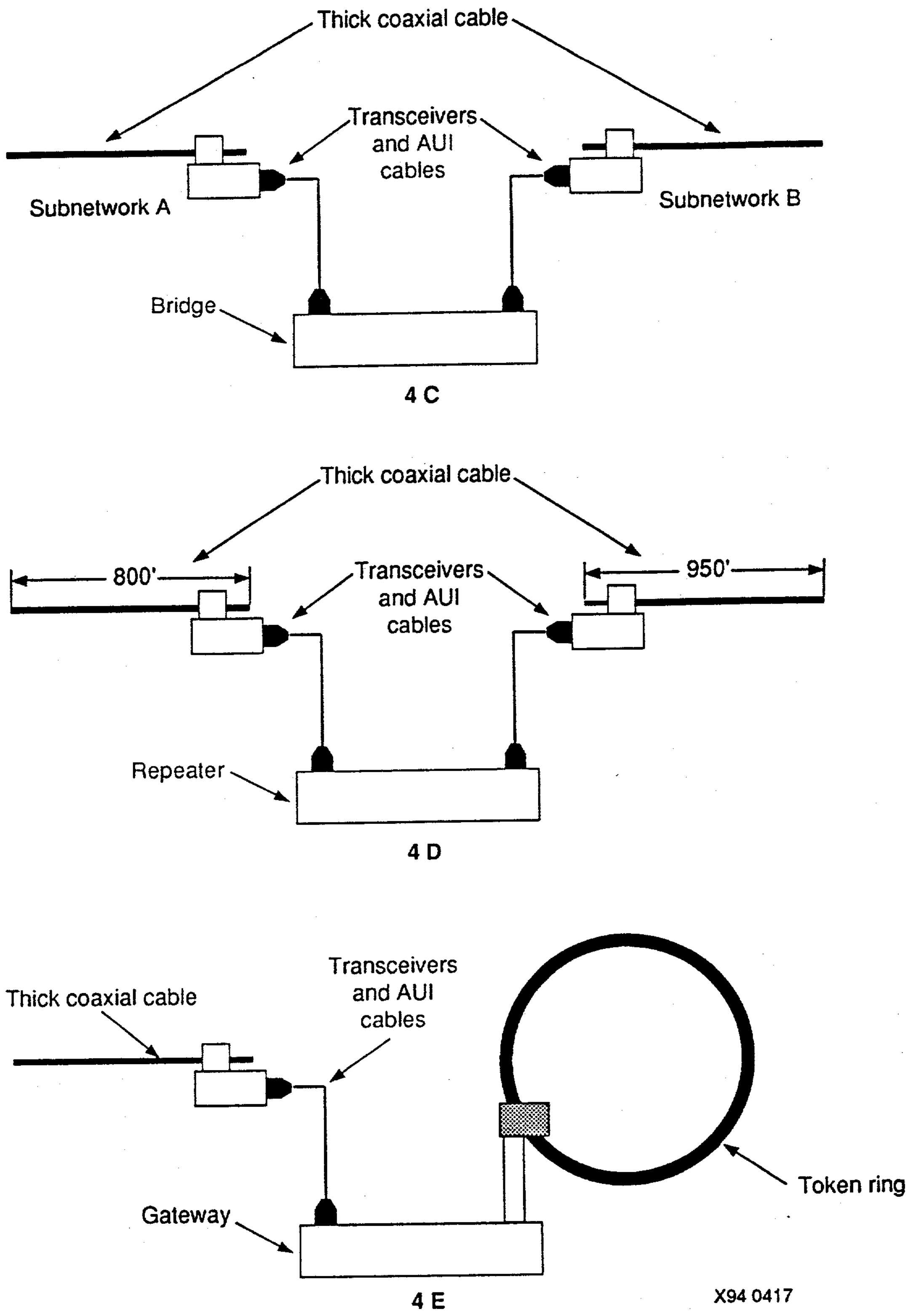


Figure 4C–E. Bridge, repeater, and gateway.

a demultiplexer; instead they use a device that filters the appropriate signal and sends it to a specific node. The advantage of filtering is that a node can be moved anywhere along the broadband system. They become geographically independent.

Another technique for combining signals on a broadband network is through time-division multiplexing. The theory involves separating each signal into discrete time divisions. These time divisions are combined in a sequential order and broadcast at the same frequency. This technique is not used as frequently as frequency multiplexing, but it does work just as well in some situations.

K-3.4 Network Technologies

A network topology is a geometrical arrangement of computer resources and communications facilities. Networks are composed of nodes, or endpoints, and links. There are five basic types of arrangements and each are functional in many different situations (see Figure 5). Most LANs utilize a "broadcast" technology in which all data are transmitted to every station. However, a station will not react to a message unless it contains the correct address of that particular station. Most LAN topologies are either

1. Baseband
    a. Daisy Chain
    b. Star
    c. Bus
    d. Mesh
2. Broadband
    a. Tree.

K-3.4.1 Daisy Chain

In the daisy chain configuration, the nodes are connected in a closed loop configuration. Nodes are able to transmit and receive data in either direction, but data must pass through all of the nodes between the receiver and sender. Messages on the network travel around the loop until they reach the address of the respective node. If the message completes a revolution and the addressee is not found, then it is returned to the transmitting node. Each node needs to be capable of recognizing its own address, as well as retransmitting messages addressed to other nodes. Generally, daisy chains operate best with a small number of nodes and over short distances.

Ring topologies are categorized by the type of transmission method employed. One common transmission type is token passing. For these types of networks, a token is passed around and only the node with the token can transmit data. If there are two nodes wanting to send data at the same time, only the node with the token can transmit its information. The node without the token has to wait.

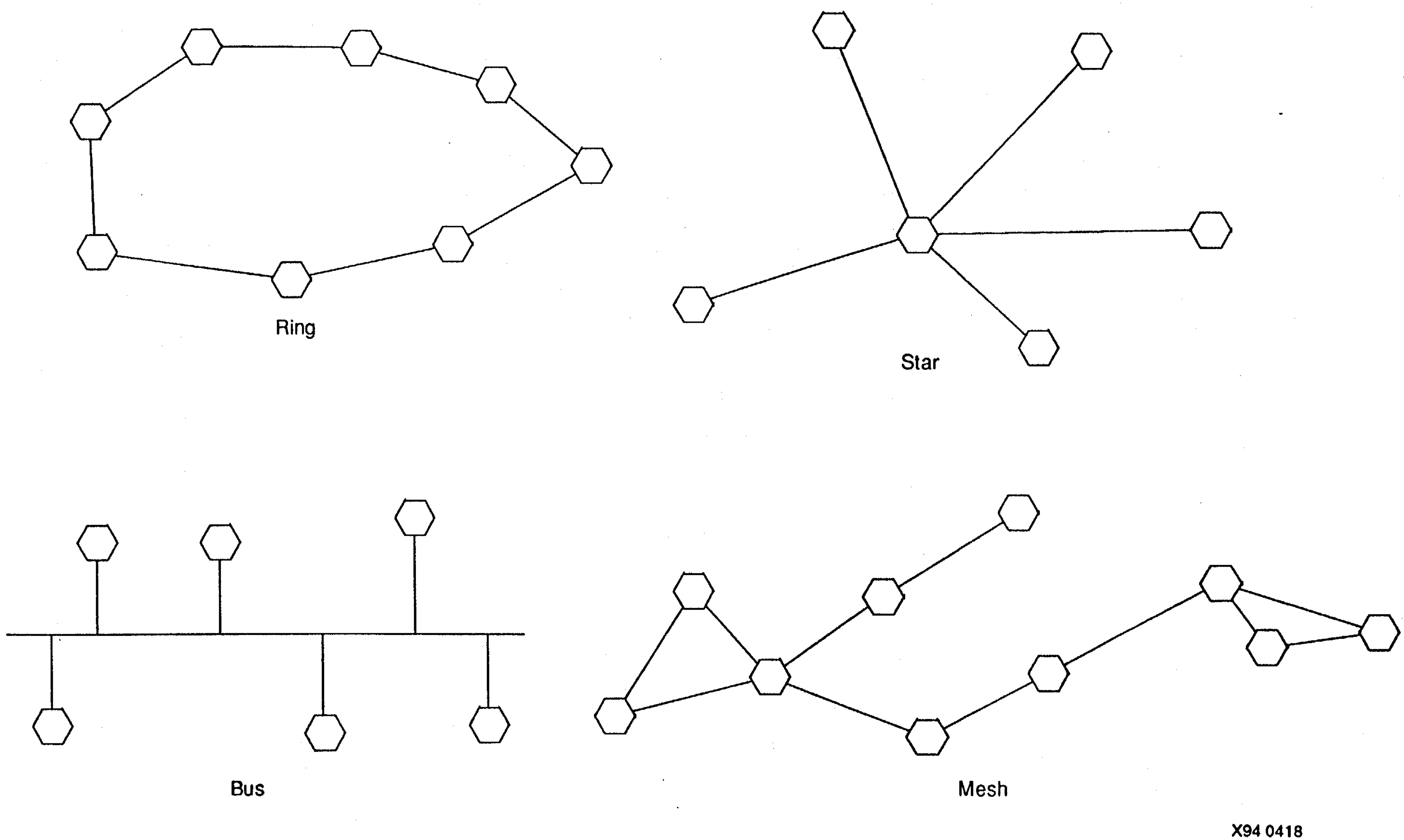


Figure 5. Topologies.

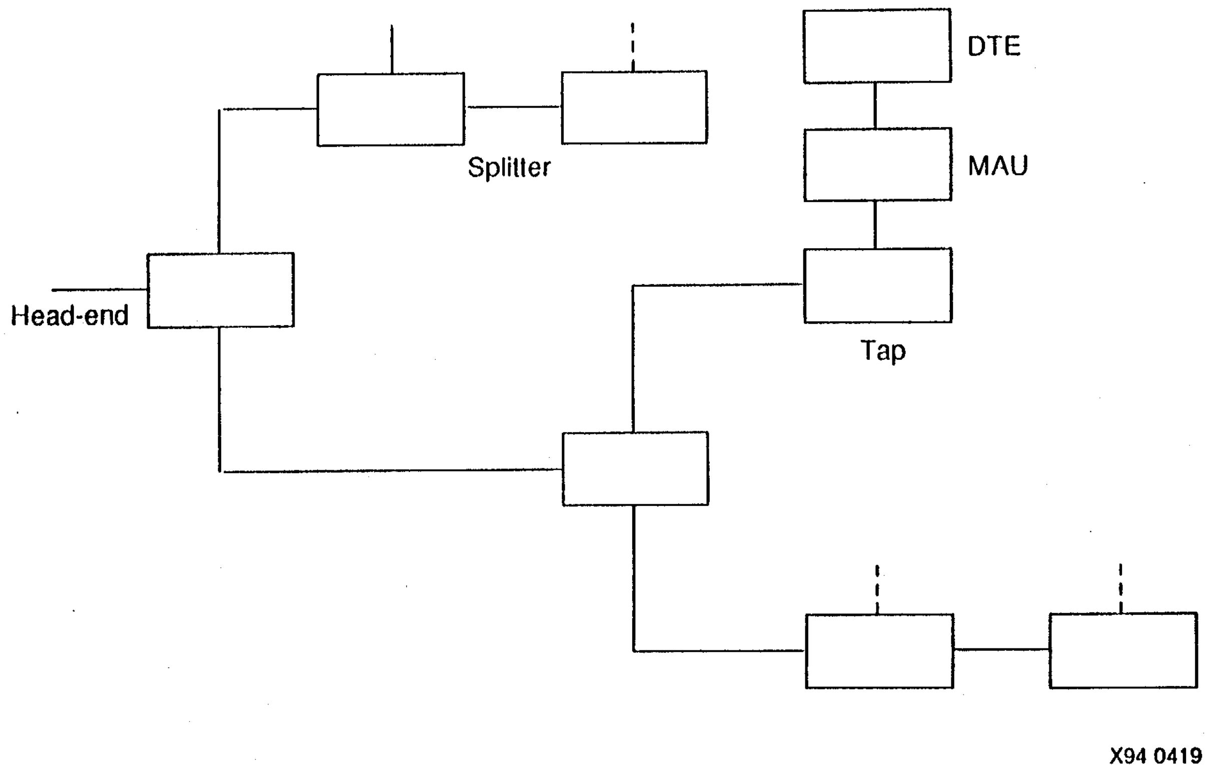


Figure 5. (continued).

Performance of a ring network is dependent upon the message transmission mechanism. Simplistic transmission types may require fewer hardware components but also cause long delays when the network is busy. A single node failure on a ring network can give rise to access loss or even total system shutdowns. Nevertheless, if a ring topology is well designed, it will prove to be an effective network solution.

K-3.4.2 Star

The star topology consists of several nodes connected by a central hub. The central node controls and routes all traffic on the network. All star networks can be classified as either message or circuit switched.

A circuit switched network is similar to a private branch exchange (PBX), a private telephone system. Most large companies use a PBX to route telephone calls in, out, and within the company. They establish a link between the transmitter and receiver on demand and hold the connection until the circuit is terminated.

A message switched network is similar to packet switching. Although, with a message switched network, the entire message is transmitted to a temporary storage location before it is retransmitted to its destination. Most star networks use this store and forward technique because the nodes of the network are usually located a considerable distance apart. The typical speed for a software implemented switching network is up to 56 kbps while handling 2,000 to 4,000 concurrent circuits.

K-3.4.3 Bus

The bus topology is currently the most popular form of networking. It is simple to initiate and is effective when implemented using coaxial cable. The bus topology uses network nodes to connect a linear length of cable and each node is defined by a unique address for easy data routing.

The performance of a bus network is based on bandwidth, number of nodes, peak user traffic, and access protocols. Bus networks are a viable network solution, although they do require a well designed collision control system to avoid failures.

One such avoidance system is the carrier-sense multiple-access with collision detection (CSMA/CD). Using this system, terminals "listen" before they transmit data and then send data only if they sense there is no other signal already in existence on the bus. If the terminal senses that the system is in use, it waits for a short period before it checks again. Collisions are detected by monitoring to determine if the transmitted data was corrupted by simultaneous transmission.

The most well known CSMA/CD bus network is Ethernet. In fact, Ethernet is so well known it is used to describe all CSMA/CD networks, even though it is only a brand name. The major benefits of an Ethernet are its low connection costs, flexibility, and large user base. Disadvantages are its low transmission speed (10 Mbps) and lack of tools to predict traffic overloading.

Ethernet uses packets to transmit data. Each packet contains the source and destination address, packet type, synchronization bits, data, and cyclic redundancy check (CRC). A CRC is an error detection scheme that treats a message as an N-bit polynomial. Using a generator polynomial, the

N-bit polynomial is divided to produce a quotient and remainder. Then, only the remainder is sent along the data highway and checked at the receiver.

The maximum length for an Ethernet is 500 m and can allow up to 100 tap transceivers. The transceiver connects the user to the data highway. For larger systems with longer lengths and more taps, repeaters are required.

An Ethernet is a good, economical network. It is fairly efficient, although access is based on the statistical laws of chance. In a large network, this could be a problem.

K-3.4.4 Mesh

The mesh is the combination of all topologies. It can be made of point-to-point and multiport data links creating redundant data paths. The geometric connections create shapes that can vary from one network to another.

Mesh networks tend to be difficult to control. In fact, they require complex routing techniques to avoid collisions. Mesh topologies are not widely used for LANs but are usually designed for long-haul packet networks.

K-3.4.5 Tree

A variation of the bus is a tree topology. It is almost exclusively used in broadband networks. The tree begins with the head-end and branches in a tree-like fashion to connect the subsystems hardware. This topology is similar to the type used in cable television systems.

The topology uses 75 Ohm cabling with aluminum shielding. The signals levels are calculated during the design stage, based on attenuation and number of taps. Amplifiers are used to maintain the signal levels.

K-3.5 Transmission Mediums

There are many types of transmission mediums. Some of the most common are thin and thick coaxial cable, twisted-pair cable, plastic or glass fiber optic cable, and radio frequencies. Each have different benefits and liabilities that meet the needs of almost any system. There are two categories of transmission media: bounded and unbounded. Some types of bounded media are coaxial cable or fiber optics. Unbounded media can be radio waves, microwaves, or infrared transmission. Most LANs use a bounded transmission medium.

K-3.5.1 AUI Cable

AUI cable is probably the most commonly used cable. It consists of eight twisted pairs of wires and a 15 pin D plug. AUI is used to connect peripherals to a computer's RS-232 port. The cables are not very flexible and connectors are marginal at best. The maximum length for AUI cable is 164.5 ft (see Figure 6).

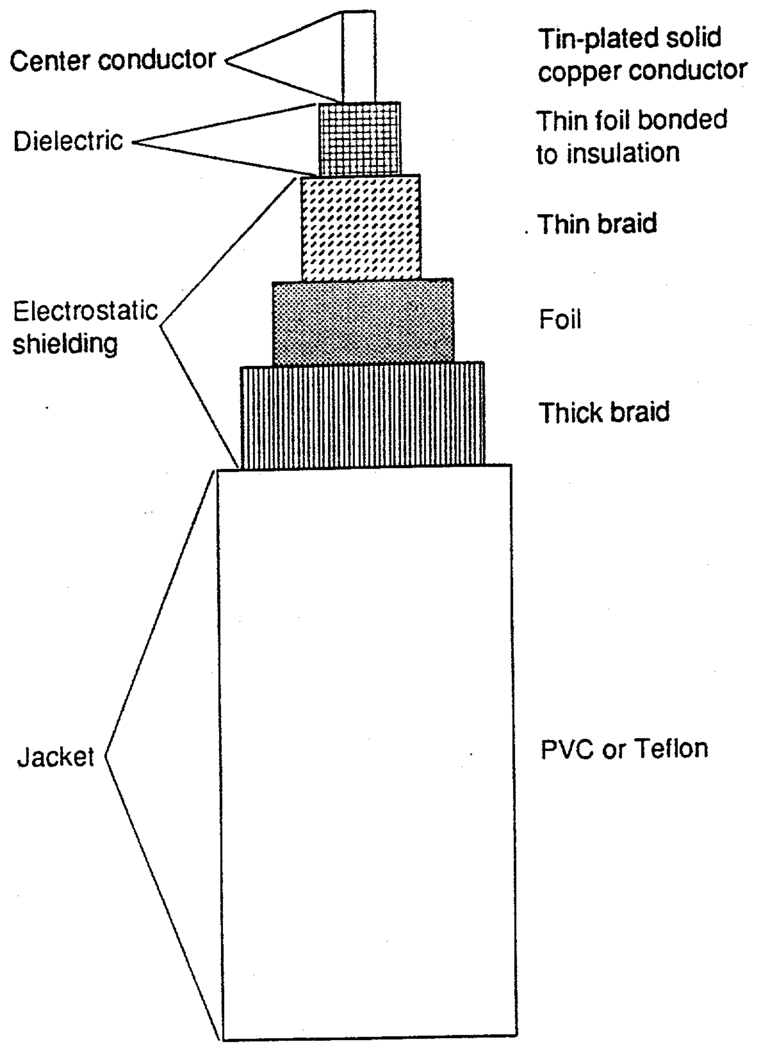


Figure 6. AUI cable assembly.

K-3.5.2 Thick Coaxial Cable

Thick coax cable is most often used as a backbone for a network. In fact, it is the cabling scheme almost always used by the bus topology. This cable is sometimes called 10 Base-5, which stands for 10 Mbps with a maximum length of 500 m without a repeater.

The cable consists of a dielectric material covering a single copper center conductor. This is surrounded by a thin braided shield, followed by a polyvinyl chloride, or teflon jacket (see Figure 7). Due to the thickness of the cable, it is difficult to work with, therefore, it is marked every 2.5 m for a tap attachment. The taps should not be placed any closer together, because they may cause excessive reflections on the network and data errors.

K-3.5.3 Thin Coaxial Cable

Thin coaxial cable, or 10 Base-2, applications are commonly called thinnet or cheapernet. Besides being lower in cost, the thin coax does have a few other advantages.

1. The cable does not have to be pierced in order to place a tap on the cable.

2. For an Ethernet, the transceiver is located on the controller card, as opposed to an external device. A transceiver is an intermediate device that transmits and receives the data from the Ethernet controller and places it onto the cable.

There are also a few limitations of a thin coax cable. The number of stations on a single cable is only 30 and the maximum length is 185 m. Also, stations may be placed no closer than 0.5 m from each other.

K-3.5.4 Twisted Pair

The use of twisted-pair cable, or 10 Base-T, is becoming popular for 10 Mbps transmission. The advantages of the cabling are many, and it is effective for Ethernet networks. Unlike coaxial cable, twisted pair uses a point-to-point scheme and a star topology. It consists of four strands of standard telephone wire and can be run 100 m without a repeater. The popularity of this cable scheme is due to the extremely low cost and availability of the cable as well as network management tools. Large networks use twisted pair because if the cable that links a station with its repeater is damaged only that station is shut down. With thick or thin coaxial cable, all stations attached to that cable will be inhibited.

K-3.5.5 Fiber Optics

Fiber optic cable has a central core with a high index of refraction. There is a cladding layer that surrounds the core composed of a material with a slightly lower refractive index. This is used to separate the core from the other fibers. Each fiber provides a single, unidirectional, end-to-end transmission path. Lasers and sometimes light emitting diodes, LEDs, are used to transmit the light wave. Fiber has a practical data rate of up to 50 Mbps and can be transmitted a distance of 6 miles without repeaters. There are two types of fiber optic cable: plastic and glass.

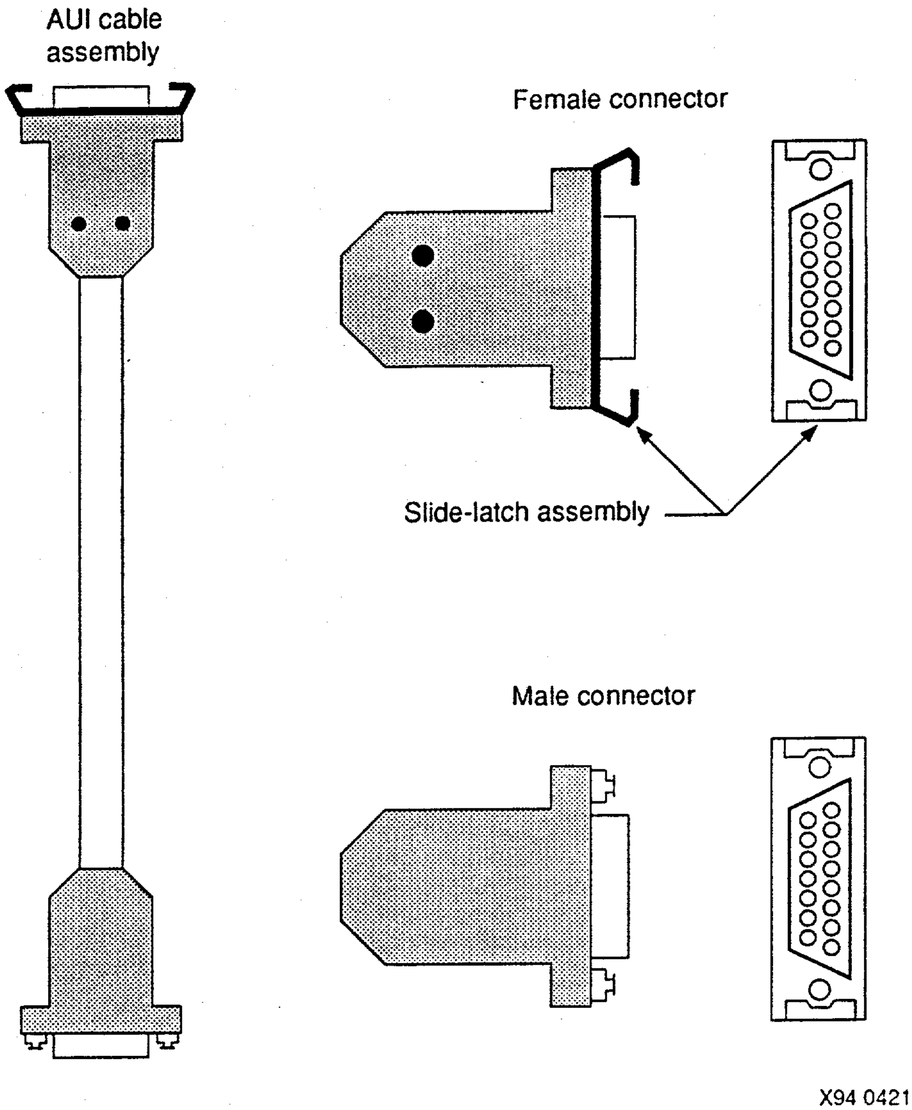


Figure 7. Cross-section of coaxial cable.

Plastic fiber is more resilient and easier to handle than glass fiber. It has excellent immunity to EMI and RFI. The disadvantage of plastic fiber is the high attenuation and low bandwidth when compared to glass fiber.

Glass fiber must be handled with care and it is difficult to install. When terminating or adding a tap to the cable, a fiber specialist must polish and inspect each strand before the connector can be added. This process requires a lot of time and money. Another disadvantage of glass fiber is that it degrades over time. The optics become discolored due to the heat and cold causing a decrease in bandwidth. Although glass fiber does have a few drawbacks, the benefits are definitely noteworthy. It is impervious to EMI and RFI, and it offers the ability to be used in long lengths without a repeater.

K-3.5.6 Radio Transmission

In many situations, radio transmission is an undesirable method for sending data. It is greatly influenced by many types of interference. However, its main advantage is that it is geographically independent within a signal area and multiple users can receive it without signal loss. The strength of a radio signal depends on the power of the transmission tower, which could be governed by the Federal Communications Commission. Despite the major drawback of interference, radio broadcasting is a viable option when conditions are unfavorable for any other type of transmission medium.

Appendix L

Collision Avoidance and Supervisory Control Resource Report

Industry Resource Summary (Preliminary as of May 12, 1994)

Appendix L

Collision Avoidance and Supervisory Control Resource Report

Industry Resource Summary (Preliminary as of May 12, 1994)

Methods to ensure Collision Avoidance (CA) for the Buried Waste Integrated Demonstration (BWID) program are currently being investigated by the Supervisory Control System (SCS) team in three areas. These three areas can best be defined as (1) Onboard CA Systems, (2) Remote Sensing and Positioning CA System, supported by computer modeling, and (3) a hybrid combination of 1 and 2.

Preliminary investigations have determined that there are many companies addressing CA, by using noncontact and onboard sensor systems, and companies supplying remote sensing positioning systems. Some are systems houses providing complete solutions, and some provide components that support complete solutions. An attempt has been made to reduce the many identified systems to a few systems that warrant further investigation. The following information summary, gleaned from the information we currently have, includes brief descriptions of the systems that offer the best promise of applicability to our defined collision avoidance task.

1. Onboard Collision Avoidance

   The Onboard CA Systems include equipment mounted on the mobile platform and references all sensing and warning data to the mobile platform for stand alone use. A mobile platform is defined as any of the vehicles or mobile systems or equipment supporting BWID process that moves under remote control. As referenced in the BWID project, these mobile platforms typically include the crane with manipulator arm, excavator, and conveyance system. The CA system on each mobile platform will provide sensing and position data to the system remote operators via onboard sensors and telemetry systems that warn the remotely located operator, via visual or audible signals, of the possibility of eminent collisions. The CA system on a given mobile platform typically knows nothing about the immediate position of any other mobile platform or object, except when these foreign objects come into the detection range of its own sensors. At that point the operator, will determine and take corrective action.

2. Remote Positioning Systems

   Remote Sensing and Positioning CA Systems rely on positioning beacons strategically located on each mobile platform, and multiple beacon sensing receivers located on the periphery of the dig area, to physically identify the platform position and orientation. The several sensing receivers typically identify relative distance to the beacon or beacons. The host processor, using trigonometric relationships, calculates the x y z coordinates of the beacon or beacons located on the platform. With each platform located computer modeling of both the platform and exclusion zones surrounding the platform are generated and maintained by the host processor. This modeling information is then used to perform collision avoidance tasks. Typically no sensing or processing equipment resides on the mobile platform.

L-1. ONBOARD CA SYSTEMS

Typically noncontacting onboard sensing and ranging technologies fall under several categories of equipment. These categories are

- Proximity
  - Magnetic
  - Inductive
  - Capacitive
  - Ported coax
  - Ultrasonic
  - Optical
    - Break-beam
    - Reflective
    - Diffuse
- Triangulation
  - Stereo disparity
  - Active triangulation
  - Structured light
  - Known target size
- Optical flow
- Time of flight (TOF)
- Phase shift measurement
- Frequency modulation
- Interferometry
  - Fringe counters
  - Diffraction gratings
- Swept focus
- Return signal intensity.

The following is a presentation of several onboard collision avoidance systems.

L-1.1 Proximity Sensors (Range Typically Under 2 ft)

L-1.1.1 Capacitive Field Proximity Sensor

See Figure 1 for design detail.

A capacitive reflector proximity sensor developed by NASA Goddard Space Flight Laboratory has been used to produce a proximity-sensing skin for use on a electronically grounded robot arm. The sensor is a capacitive-sensing element backed by a reflector element. Both the sensor and reflector are driven by the same voltage. The field lines from the sensor that would ordinarily return to ground are prevented from doing so by the reflector. These field lines are reflected back towards the object being sensed, effectively enhancing sensor-target capacitive coupling. Maximum detection range is 18 in.

L-1.1.2 Ported Co-ax Proximity Sensor

See Figure 2 for design detail.

Ported (leaky) coax detector systems have long been used for security system intrusion detection. The sensors for these systems consists of two ported coax cables parallel buried a few feet apart, and a few inches below an earth surface. The coax cables form a perimeter around the area to be secured. A radio frequency (RF) signal is induced into one coax, and the other coax functions as a detector. The earth surrounding the cables serves as a sort of a necessary control medium so that the surface wave is rapidly attenuated. The field produced by this surface wave is highly susceptible to any object moving through it. Moving objects within the field are detected by comparing the signal transmitted on one cable to the signal received on the other. The problem confronting the use of ported coax aboveground is duplicating the moderating effect of the earth surrounding the cable. INSTANTEL, a communications company in Ottawa, Ontario, Canada, has successfully demonstrated a ported cable configuration that, to a degree, simulates the buried in earth surface wave attenuation, and can be used in an aboveground applications. In this aboveground configuration the transmit and receive coax cables are located side by side and a grounded, fine steel wire is tightly spiral wrapped around the cables. The spiral wrapped sense element can be tens of feet long, and if backed by a grounded, conductive reflector, can conform some what to the shape of the system being protected. Maximum detector range is typically 4 ft.

L-1.2 Look Ahead Sensors (Range up to 60 ft)

L-1.2.1 Cybermotion Ultrasonic Collision Avoidance System CA-2

The CA-2 Collision Avoidance System is a dual-channel ultrasonic ranging module developed by Cybermotion, Inc., Roanoke, Virginia, for use on indoor vehicles operating at speeds up to 10 mph. The CA-2 achieves a maximum detection range of 8 ft, with programmable resolution over the span of interest.

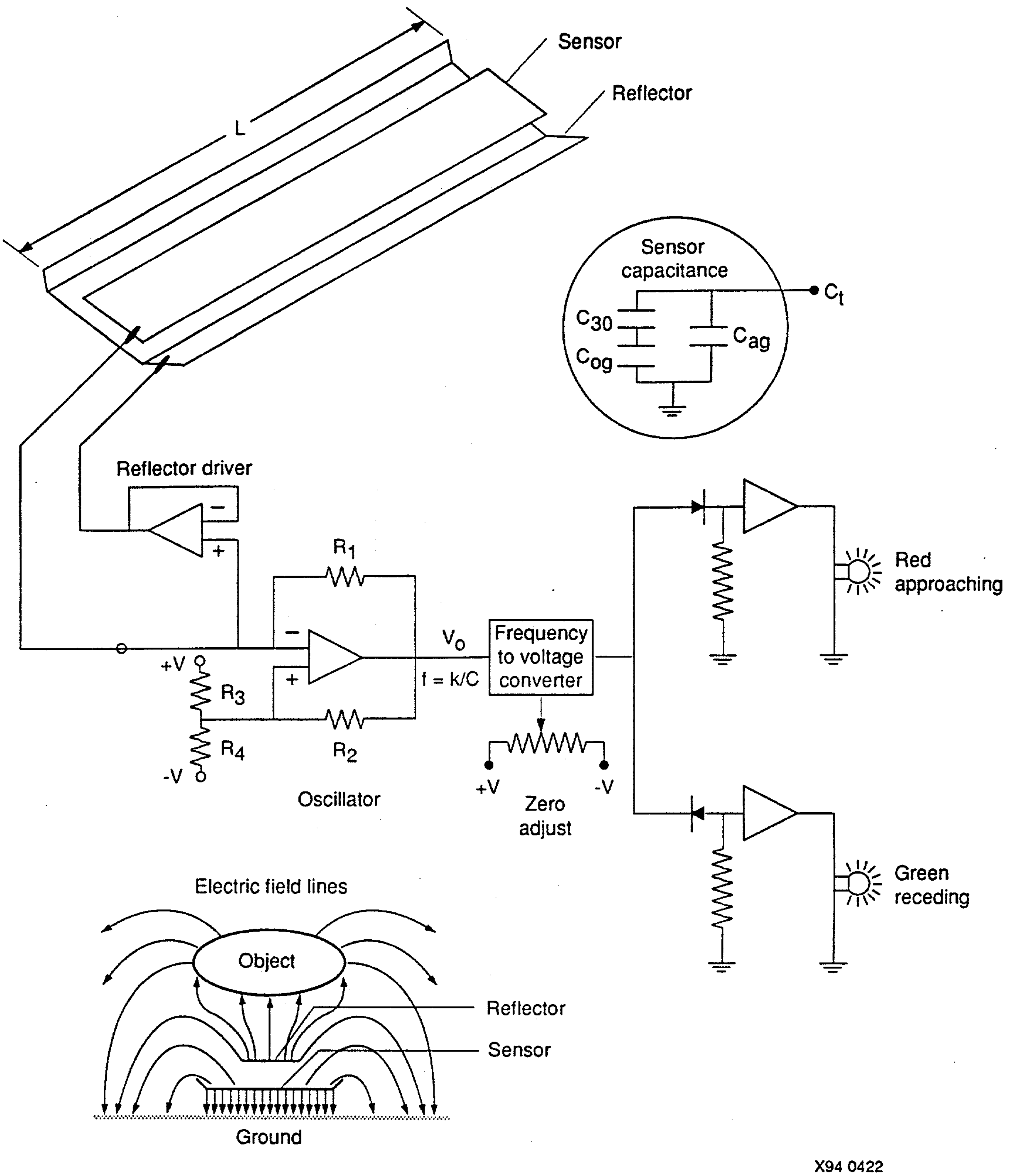


Figure 1. Capacitive field proximity sensor.

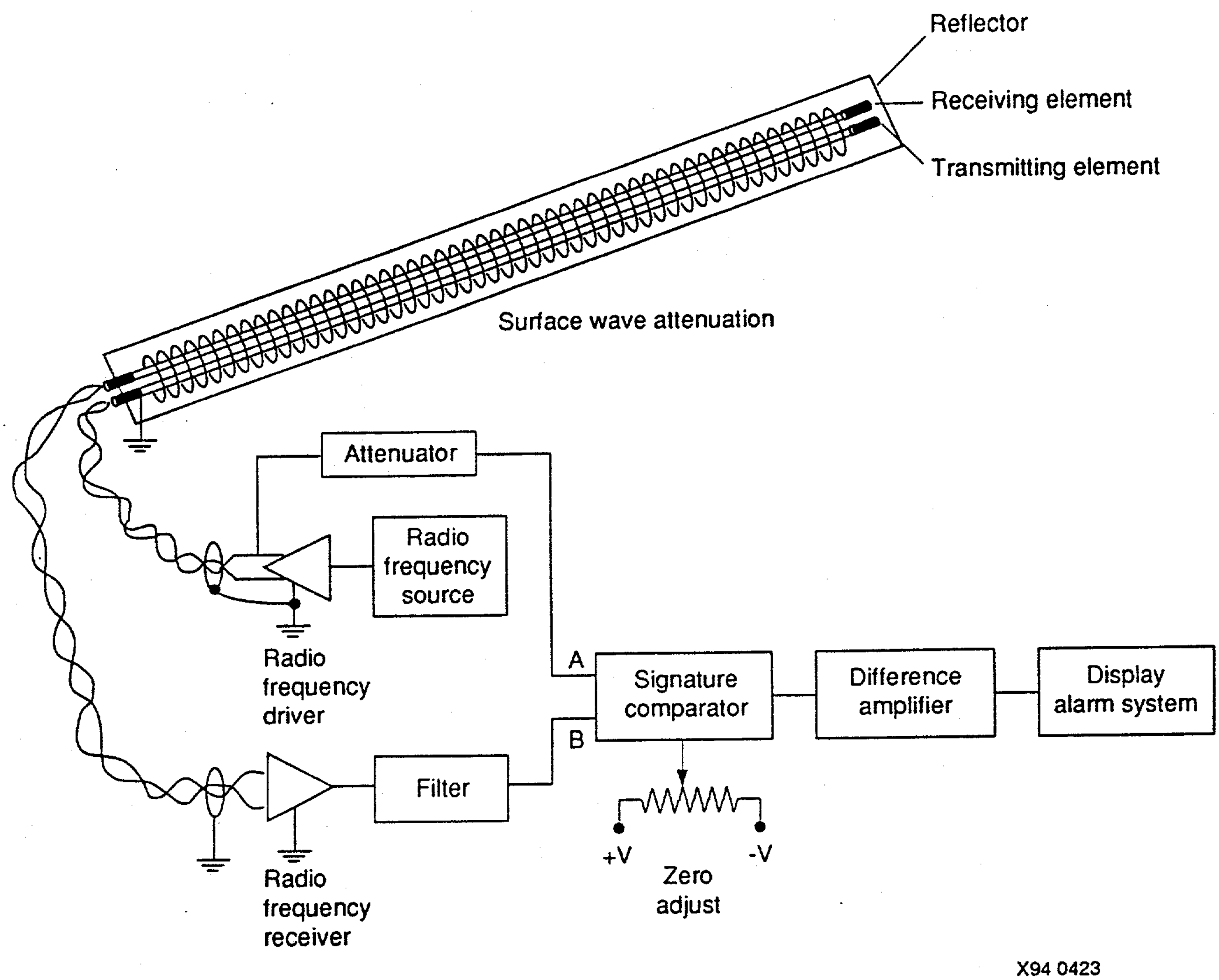


Figure 2. Ported coax proximity sensor.

Selected Specifications

Ranging technique	Ultrasonic Time of Flight
Maximum range	8 ft programmable
Minimum range	1 ft
Update rate	up to 10 cps
Resolution	0.084 in. (standard)
Operating frequency	75 KHz
Number of beams	2
Beamwidth	70-degree cone
Power consumption	11.5 to 14.5 volts at 150 ma
Size	1.2 by 8.1 by 5.85 in.
Sensitivity	Programmable to 1 square in. surface at 5 ft

L-1.2.2 Polaroid Ultrasonic Ranging Unit

The Polaroid Ultrasonic Ranging module is an active time-of-flight device developed for automatic camera focusing, and determines the range to target by measuring elapsed time between ultrasonic transmission and the detected echo. The system operates in the transceiver mode so that only a single transducer is necessary to acquire range data. Polaroid offers both the transducer and ranging module circuit for less that $50. The transceiver transmits a 1-millisecond chirp, consisting of a discrete 49.1 KHz frequency burst. Timing the echo begins at the start of the chirp. The detection range of the Polaroid system runs from about 1 to 35 ft, with a beam dispersion angle of approximately 30 degrees. The module circuit board part number is SN28827.

L-1.2.3 Banner Near-Infrared Proximity Sensor

Banner Engineering, Minneapolis, Minnesota, offers a full line of modular near infrared proximity sensors of the break-beam, reflective, and diffusion type. Effective ranges vary from a few inches out to 7 ft. Robotics applications include floor sensing and collision avoidance.

L-1.2.4 TRC LABMATE Proximity Sensor System

Transition Research Corporation, Danbury, Connecticut, offers a Proximity System using Polaroid ultrasonic range finders and Banner near-infrared diffuse-type proximity sensors. The basic system consists of a central processing unit and interface card, each capable of handling eight ultrasonic and eight infrared sensors. The CPU can control up to three interface cards. Typical ranges are from 9 in. to 35 ft, with accuracies to a few inches.

L-1.2.5 TRC Light direction and Ranging System, LIDAR

Transition Research Corporation, Danbury, Connecticut, has developed a low cost light direction and ranging system (LIDAR) for use on mobile platforms. The sensors detect obstacles in the vicinity of the mobile platform and estimates the platforms position from local landmarks or from beacons in the environment. LIDAR projects a modulated beam of near-infrared light into the target area. A large area lens gathers the light reflected back from a target object, and compares the modulation phase of the returned light with the transmitted light. The result is a measure of the round-trip distance to the illuminated object. The system employs a 2D scanning mechanism. A mirror is mounted so that it rotates 360 degrees around at 10 Hz, and nods simultaneously from 0 down 45 degrees, then back up to 0 degrees at 1 Hz, under the power of a single motor. The effect is to create a protective spiral of detection around the mobile platform.

L-1.2.6 VORAD Vehicle Detection and Driver Alert System

VORAD Safety Systems, Incorporated, a subsidiary of IVHS Technologies in San Diego, California, has developed a high frequency radar system designed for onboard use on a mobile platform. A 5 × 5-in. rotating antenna, mounted on top of the platform, monitors speed and distance to other platforms or objects. A control panel is provided that uses a series of caution lights and audible beeps to alert the operator of potential hazards.

L-1.2.7 National Semiconductor's LM1812 Ultrasonic Transceiver

The LM1812 is a general purpose ultrasonic transceiver designed for use in a variety of ranging, sensing, and communications applications. The chip contains a pulse-modulated class-C transmitter, a high-gain receiver, a pulse modulated detector and noise rejection circuitry. Two different types of ultrasonic transducers (electrostatic and piezoceramic) are used with the LM1812. Both transducers transmit an outgoing signal and act as a microphone to receive reflected signals. Effective maximum range is 20 ft.

L-1.2.8 FMC Ultrasonic Imaging Sensor

The FMC ultrasonic imaging sensor is an obstacle detection and collision avoidance system. The device is a phased-array sonar system with four piezoelectric transmitters and an array of 16 microphones positioned in a half circle across a 180 degree field. The system functions as a direct-measure time-of-flight ranging device. Sound pulses are sent out and returning echoes detected from objects between 2 and 50 ft away.

The above systems have been described in brief detail. Some systems are commercially available approximately as described. Some are provided as OEM to a systems developer. In all cases, additional investigation must be made to determine what is available as a commercial product.

L-2. REMOTE SENSING AND POSITIONING SYSTEMS

The remote sensing and positioning CA systems rely on beacons, strategically located on each mobile platform, and a triangulation scanning system capable of locating the beacons in 3D space to physically identify each platforms position and orientation. Each beacon has a unique identifier and its location information is transmitted several times each second, by the scanning system, to a computer modeling data base. The computer data base maintains a 3D model of each mobile platform. Based on the beacon location information, the data base updates the location of the displayed model, including intrusion perimeter boundaries, for each mobile platform functioning in the dig area. If projected intrusion perimeters make contact, the operators of the intruding systems are alerted to initiate collision avoidance measures. These avoidance measures are aided by 2D and 3D computer displays of the intruding systems automatically made available to the operator.

Two different 3D avoidance zones are maintained by the data base around each platform. The outer zone extends approximately 4 ft beyond the actual physical boundaries of the platform. This zone is considered the yellow or caution zone. If yellow zones from separate mobile platforms make contact, operator action to guard against collision is invited, but it is optional. The inner boundary surrounding the mobile platform extends approximately 18 in. beyond the platforms physical boundaries and is considered the red or emergency zone. If two red zones make contact, operator action is required. In addition, for red zone contact, the data base includes drivers that control external relay closures that can be used to shut down the offending systems. In the event that the intrusion is necessary or intentional, an operator override function is provided.

Typically no sensing or processing equipment resides on the mobile platforms except for the beacon, thus minimizing the risk of system maintenance in a contaminated area.

The following remote sensing and positioning systems are presented for consideration:

L-2.1 Radio Frequency Systems

- Harris Technology Inc. (HTI), Washington, D.C., would integrate existing MDARS (U.S. Army) system to our application. Incorporated a master control station that monitors (video and audio), tracks (location, orientation, and status) and remotely control multiple mobile robotics vehicles. HTI infogeometric products and systems encompass virtually all aspects of the robotization, instrumentation, monitoring situation awareness and command and control. (See a more detailed discussion in Attachment 1).

- Robotics System Technology (RST), Westminster, Maryland, uses HTI technology under Department of Defense contract to develop MDARS. Two main components are accurate positioning location system and collision avoidance system.

- Lockheed Sandars, Inc., Nashua, New Hampshire, uses a Precision Navigation, homodyne microwave receiver/transmitter using a CW carrier that is FM chirped, in a linear manner, so that the instantaneous difference frequency (received versus transmitted) is directly translated to range. Inch accuracy, 400-ft range, update rate much greater than 10 Hz.

- Bingham and Anderson, INEL. A time varying electromagnetic signal with a frequency ranging in the spectrum from RF to microwave, will be used. An RF transmitter that will emit a very low power RF signal must be implemented on each object, or physical point on the object, whose position coordinates are to be monitored. To allow for 3D position data to be determined, four fixed receiving sensors/antenna must be located around the periphery of the region of interest. Each emitter will be coded with a unique identifier. Location, based on time-of-flight, will be calculated by a central processor. (See a more detailed discussion in Attachment 1).

L-2.2 Laser

MacLeod Technologies Ind., (MTI), Chelmsford, Virginia, uses laser-based tracking system and traffic control software. Tiny passive sensors, strategically mounted on each piece of equipment, provide precise position awareness for automated collision avoidance. Software tracks location of everything marked with sensors in real time. (See a more detailed discussion in Attachment 1).

L-2.3 Acoustic

HTI has an acoustic scanner that has the capability to map a 360 degree terrain, surrounding the source vehicle, to 2-in. increments within 400 yd based on line-of-sight acoustic time-of-flight chirps.

L-2.4 Video

- Kenetic Sciences Inc., Vancouver, British Columbia, uses Eagle Eye, a video camera based identification and tracking system. Using stored size and shape information and recognized feature edges, calculates location and attitude of 3D marker of a specified size and shape and unique identification number.

- GEC (UK General Electric Company) has developed a Real-Time Gaze (RTG) control that uses two cameras capable of focusing on a target like the human eyes. Knowing the distance between the cameras and the relative center axis angle between the two cameras, the range and location of the target can be calculated.

- Omniview is a camera tracking and ranging system by TeleRobotics International, Inc. The Omniview system, provides multiple, simultaneous images from two video cameras situated in designated directions within a hemispherical field-of-view for display or analysis without moving parts. As a result, a large coverage volume can be scanned with a minimal number of cameras. Two Omniview systems will provide plan view and front view coverage of each mobile system. The operator will use the front view to select the destination of the next motion and use the plan view to designate the distance to the ending location. In this way, the operator will be able to "fly" the mobile platform to an end location by simply selecting the end location on two monitors. The control system determines the direction for movement, redirects the mobile platform along the line of movement and initiates a sequence of motion constraints, based on an area map, to minimize the potential of collision between the mobile platforms and working environment.

L-2.5 Global Positioning Systems

- Allen Osborne Associates (AOA) of Westlake Village, California, specializes in the design, analysis, development, and production of military and commercial equipment in the fields of NAVSTAR Global Positioning Systems (GPS) for positioning, navigation and timing, communications, and robotics. Working with Ohio State University, using TurboRogue Technology, AOA achieved centimeter level accuracies in real time to pinpoint the position of the cutting blade of earthmoving equipment.

- Gnostech Inc. is a specialist in GPS technology and applications, custom electronics/prototyping, real-time simulation and reliability engineering.

- Trimble Associates.

- The Pennsylvania State Transmit Internodal Positioning System (TIPS) is GPS based and supported by auxiliary systems.

- ARINC Research Corporation performs studies, analysis, design, development, test, evaluation, and support of complex systems. It is currently developing a high precision positioning system (in the order of 3 cm) for Hughes Aircraft Co., using kinematic GPS carrier phase tracking.

- Now Solutions, Inc., has developed a GPS based communications system using Automated Equipment Identification (AEI) tags for managing and tracking the movement of internodal freight containers in major U.S. and international seaports, rail yards, truck depots, and air cargo terminals.

L-3. COMMUNICATIONS

L-3.1 Broadband Cable Available to All Locations (INEL Provided)

Video and data support are provided.

L-3.2 Other Video Systems

1. Jet Propulsion Laboratory (JPL), Pasadena, California, performs research on video stereo vision based real-time collision avoidance systems.

L-4. SOFTWARE SYSTEMS

L-4.1 Systems Modeling

ISE Ltd., Canada, has a software product that is used for both graphical simulation and on-line robot control. The software package called ACT, for example, gives to a manipulator, trajectory planning, and obstacle avoidance capabilities, based on input of computer vision and laser sensing information.

L-5. SYSTEMS INTEGRATOR

L-5.1 INEL/EG&G IDAHO

- Oceaneering Technology, Inc., (OTECH), Upper Marlboro, Maryland. Design, assembly, manufacturing, integration, test, and operation of remotely operated vehicles, work packages, marine handling systems, tooling, telerobotic interfaces, deep water systems, and manual systems.

- SRI International (Stanford Research Institute), Menlo Park, California. Integration planning and control, artificial intelligence, representation and reasoning, computing, robotics, approximate reasoning, fuzzy logic, evidential reasoning.

- Jet Propulsion Laboratory (JPL), Pasadena, California. Research on robotics vehicles, unmanned ground vehicle reconnaissance applications and robotics excavation, stereo vision based real-time collision avoidance systems.

- International Submarine Engineering Ltd., Port Coquitlam, B.C., Canada. Autonomous robotics program and trajectory planning, obstacle avoidance, and force control program for Canadian government would be adapted to BWID.

- McDonnell Douglas, Aerospace Division, Houston. Experts in developing robotics applications for space operations in extremely harsh environments, using highly precise real-time ranging and positioning systems. Successfully employed stereoscope techniques using closed circuit television cameras and pulsed infrared emitting diode arrays. Successfully developed laser ranging systems that can accurately resolve the attitudes and position of objects.

- Barquist Engineering Co. Inc. Makes use of a number of small firms in cooperative ventures to provide the staff and talents to respond to VHF RF engineering, digital and computer circuits engineering and computer controlled machine fabrication needs. Has sensor design experience in millimeter radiometry, EHF radar considerations and EHF communications.

L-6. INTERESTED, RELATED SUPPLIERS

- Vector Design and Manufacturing. Modular mining system, software equipment and vehicle inventory control system.

- Austin Telecommunications Electronics. Delivered a document restating what they think our needs are. No apparent solutions.

- V.F. Warner & Associates. Inc. All terrain vehicles.

- Spar Aerospace Limited. Spar is a bidder on the BWID Conveyance System. Spar is currently developing control systems for Long Reach Manipulators.

- Colorado State University (CSU). CSU partnering with Denning and Branch & Associates want to bid on the BWID tracking system. Denning developed the MRV-2. Branch & Associates build teleoperated robots.

- Fredrick Herold & Associates, Inc. Heavily involved with NASA in providing space systems support. Their expertise is in analyzing future mission requirements, developing specifications, ensuring proper specification allocation for link performance, and participating in design reviews.

- Controlauto Systems Inc. (CaSI). Specialize in design development, research and transfer of Applied Control Technologies, with 8 years experience in controller design and software/hardware implementation, including intelligent and adaptive control algorithms for robotics applications.

- RedZone Robotics Inc. Supplier of intelligent, highly mobile, unmanned, ground vehicles technologies, and specialized robotics systems for work in hazardous environments. In collaboration with a third party, has access to a laser-based system that enables position and orientation to be resolved.

- CAE Electronics Ltd. Builds flight, radar, and weapons simulators and training devices for Canada and NATO. Developed a full-color, 3D, photographic image, visual simulator called MAXVUE.

- Optical Shields Inc. Has technology and breadboard demonstration equipment regarding the use of liquid crystal modulating retroreflector for two-way communication systems, and optical control devices, such as Automatic Motor Vehicle Convey Pilot System (AMVCPS).

Attachment 1

More Detailed Discussion of Selected Suppliers

Attachment 1

More Detailed Discussion of Selected Suppliers

1. INEL SYSTEM

The following is a short description of the position sensing technology that was developed at the INEL as applied to the BWID project. This technology allows a single system to track, in real-time, the special coordinates of either stationary or moving objects in 3D space. The technique is especially adapt to regions bounded by distances less than several hundred meters, where most RF-based systems fail. The application of the positioning system will be to provide position data to remote operators and control systems. The data will be used for collision control and avoidance between the crane with a manipulator arm, excavator, and conveyance system. The region of interest for the BWID project is bounded by four sides with dimensions of approximately 170 ft per side. The goal of the positioning system will be to locate objects with an accuracy of less than ±2 in. in 3D space.

A time varying electromagnetic signal with a frequency ranging in the spectrum from RF to microwave will be used. In this frequency range, the effects on the performance of the positioning system due to dust will be negligible. An RF transmitter emitting a very low power RF signal must be implemented on each object (or physical point on that object) whose position coordinates are to be continually monitored. The signal may be either continuous wave (CW), pulsed, modulated CW, or pulsed modulated. The optimum scheme for the application will be selected. To allow for 3D position data to be determined, four fixed receiving sensors/antennas must be located around the perimeter of the region of interest. The position coordinates of the fixed receiving antennas, with respect to some reference, must be known. An additional sensor may be required to achieve the needed accuracy. In order to enable identification and discrimination between emitters, each emitter signal must be coded with an identifier or used in a shared time multiplexed system. Time difference and/or phase information between the fixed sensors will be transmitted via transmission cable to a central processor. At the central processor, the data will be processed to determine the position of each emitter.

The system is fault tolerant from power failures, eliminating requirements for the re-alignment and calculation of coordinates. The system is mechanically passive in that no mechanical servo mechanisms are required. The limitation to the minimum distances from the objects being positioned to the receiver elements is dictated by the physical limitations and beamwidths, of the sensing elements. Distances of less than a meter will be permissible. Position update rates of better than 10 to 100 times per second will provide a convenient mechanism for the real-time logging of position and associated raw data.

2. MDARS AND BISON BY HARRIS

The following is a brief overview of the Harris Technologies Inc. (HTI) positioning systems.

Harris has provided a video tape of their "SW&RMBOT" system in operation, which visually demonstrates a 5 centimeter RMS indoor robotics tracking and control system. This project was performed in 1991 for ARPA—as a precursor to the currently ongoing ARPA Smart Low cost Intercept Device (SLID) project. (The SW&RMBOT is shown "running over" and catching falling copper-coated ping pong balls).

MDARS:

The current Mobil Detection and Response System (MDARS) program appears to be similar in many aspects to the currently defined BWID project. The MDARS system incorporates a master control station that monitors (video and audio), tracks (location, orientation and status) and remotely controls up to 20 mobile robotics vehicles.

The MDARS system that operates within FCC unlicensed spread spectrum bands (915 megaHz and 2.4 gigaHz), has a range tracking resolution of 15 centimeters, which is greater than the BWID requirement of ±2 in.; however, the basic design could be adapted to operate in a broader RF band to provide better resolution (centimeter-class)—provided the broader frequency allocation is permitted.

BISON:

HTI's BISON instrumentation/communication/training system, developed for the U.S. Army National Guard, incorporates a touch-screen situation display that would seem to be similar in many respects to that required by a command/control station in the BWID intended application. The situation display, which is integrated into the HTI infogeometric network, tracks and displays a potentially large number of mobile users—projected onto an earth-referenced map that shows relevant context features. Each user device is displayed with indicated ID, location, orientation, and status. Point to point commands, instructional and planning data can be sent via touch-screen entry.

HTI specializes in the development or application-specific infogeometric products and systems. Infogeometric products combine high bandwidth data communications in cost effective, common digital/RF hardware. HTI Infogeometric application products include:

- Multipath resistant robotics tracking/guidance systems; 10 centimeter/2 degree RMS accuracy (client: ARPA [indoor] SW&RMBOT and [exterior] SLID interceptor weaponization projects).

- Nonline of sight (exterior-robotics tracking/control systems; 15 centimeter/2 degree RMS accuracy at ranges up to 5 kilometers (client" NCCOSC/Mobile Detection and Response System).

- Multiuser command/control station monitoring system, including real-time voice/video and remote control link; (client—NCCOSC/Mobile Detection and Response System).

- Combat training instrumentation/situation awareness system; 10+ kilometer operational range (client—US Army Combat ID and Battle Labs).

- Hand held cellular tracking/communication devices (client—ARPA C2T2 dual use technology project).

- "Relocateable Virtual Boundary Markers" used to establish constantly changing golf course "off-limit" areas to robotics vehicles (client—GolfPro International).

Current HTI infogeometric products are designed to operate, without FCC license, in approved FCC spread spectrum frequency bands centered around either 915 megahertz or 2.4 gigahertz. RMS range tracking accuracy is typically limited in these operating bands to 10 to 15 centimeters. For special applications demanding centimeter-class precision, it would be necessary to extend frequency coverage beyond that currently available in FCC unlicensed bands.

HTI infogeometric products and systems encompass virtually all aspects of the robotization, instrumentation, monitoring and situation awareness, command and control of complex multiuser systems—in both indoor and exterior application environments.

In addition, HTI expertise in communications, radar, guidance and control, situation displays and real-time computerized monitoring/control systems make HTI a potentially valuable resource when developing demanding new application systems.

Unique demonstrated capabilities of infogeometric devices include the following:

- Infogeometric Devices Form Spontaneous, Self-Organizing Networks advantages include:

  - Mutual awareness of device identity, location, status, and intended function (e.g., TG devices can be used as "virtual boundary markers").

  - Mutual awareness permits collision avoidance, even in high congestion areas.

  - Comprehensive, quantitative mutual situation awareness instrumentation data can be recorded in an efficient infogeometric compressed-data format, for use in such applications as post-event analysis.

  - Potentially large numbers of infogeometric user platforms can be tracked and coordinated in real time without confusion.

- Infogeometric Devices Provide User-Available Point-To-Point Communication Bandwidths Approaching a Million Bits Per Second, With Independent Sharing of Available Frequency Bands.

  - Bandwidths are adequate to support concurrent data, voice and video by each network user (e.g., a useful capability for use in a central monitoring or command/control work station).

- Point-To-Point communications can be directed at a specific user device or can be broadcast as party line communications (e.g., bulletin boards).

- Infogeometric signalling codes and RF waveforms permit ultra-high resolution range and interferometric measurements; proprietary RF sensor designs are highly immune to environmental multipath effects and RF noise sources.

- Infogeometric multiuser detection codes permit potentially large numbers of users, operating in close proximity, to share available RF bandwidth with acceptably small levels of mutual interference.

3. MACCLEOD TRIANGULATION SYSTEM

3.1 Executive Summary

A priority need exists for an automated collision avoidance system for the BWID Program. Without this subsystem, significant risk for vehicle collisions exists between each other and with fixed objects. Numerous examples exist where limited sensory feedback to remote operators has resulted in vehicle collisions, entrapment, or tip over. These accidents were typically the result of operator disorientation in a congested, unfamiliar, or hilly environment.

3.2 Solution

MTI's precision laser based tracking system and traffic control software offers an ideal near-term solution for collision avoidance. This system also offers other tools that will help ensure the success of the demonstration program.

The key of MTI's low cost approach is to turn the interior of the containment building into a high-speed, precision 3D coordinate measurement area. Tiny passive sensors strategically mounted on each piece of equipment provide precise position awareness for automated collision avoidance and other integrated systems. With the provided software, the work site and everything in it is in computer memory and all equipment motion is maintained in real time, to scale.

3.3 MTI's Automated Collision Avoidance

The primary benefits of the MTI system is the ability to prevent collisions between two vehicles as well as between a vehicle and fixed objects around it. Using the known equipment positions, from the laser tracking system, and resulting equipment velocity vectors, the computer is able to check for any possible conflict throughout the site many times a second. MTI's software places a safety zone (in computer memory) around the inside of the enclosure, all equipment, tethers, holes, and snags. Whenever two safety zones overlap, the potential for a collision exists, and the computer issues an alert. The supervisory computer continuously checks for conflicts. If a conflict is anticipated, the operator(s) is quickly alerted. If no corrective action is apparent, the equipment may be promptly shut down by the supervisory computer.

3.4 Coordinate Measurement Overview (MTI proprietary data)

MTI's local area coordinate measurement capability is significantly more accurate and reliable than any other system. Components are small, low cost, low maintenance, and easy to use. The system well suited for tracking a large number of mobile datums within a single environment.

By placing MTI's specialized laser beacons (smaller than a soda can) at known locations in the perimeter of building. The enclosure building becomes a 3D measurement area. These interconnected beacons produce an invisible, high-speed, eye-safe network of scanning laser lines.

When a position transponder (smaller than a 35 mm film canister) is placed in this environment, it produces an electrical pulse each time a beacon's beam scans it. Position transponders are low power solid state devices that require only a single data line back to the tracking computer. Transponder signals may be communicated by wire or radio link.

The remote computer (usually IBM PC) processes the transponder beacon signals to produce accurate position data. One 486 computer is able to monitor many tracking transponders simultaneously. Using MTI I/O boards and software.

Any piece of mobile equipment may be tracked by attaching MTI's position transponders at known locations (datums) on the vehicle.

The equipment's shape is added to the system via DXF file from any good CAD system. One transponder on a piece of equipment provides its X, Y, and Z position. Two transponders provide X, Y, Z, positioning data as well as equipment orientation and heading. Three transponders provide X, Y, Z, pitch, yaw and roll. To provide a true position feedback for a vehicle's end effector (i.e., shovel, gripper, or bucket) simply add a transponder to each tool.

3.5 Projected System Performance

X, Y, Z position accuracy: ±0.1 in. throughout. Position update frequency for all transponders is 25 Hz (real time). Areas where position transponders will loose telemetry is none. Collision between accurately mapped vehicles or objects is none.

3.6 Summary

The MTI collision avoidance system is a practical solution to controlling collisions within the containment building. This system is also able to economically crate a real-time, telepresence work site using high quality 3D graphics. Unlike video feedback, this "virtual" environment may be viewed from any 3D vantage point, ideal for planning purposes. The system also offers important tip-over protection for excavation equipment.

MTI's low cost system will project a safety conscious, state-of-the-art imaging system for the BWID.

3.7 Vendor List BWID

3.7.1 Non-U.S./Canadian Companies

Israel

Tadiran Electronic Industries, Inc.
350 5th Ave, Suite 1925
New York, NY 10118
(212) 947-4602
% Eli Haberman

RAMTA
P.O. Box 323
Beer Sheva, 84102, Israel
972-7-280087
% Mr. Sharon David

Sieman Sensors & Intelligent Machines Ltd.
MTI-Misgav, D. N. Misgav 20179
972-4-906888

Germany

System Gesellschaft mbH
P. O. Box 93 33
D-24157 Kiel, FRG
Phone-431/3995-02
% Mr. Wende

3.7.2 U.S./Canadian Companies

1. MacLeod Technologies Inc,
   313 Littleton Rd.
   Chelmsford, MA 01824
   (508) 250-4949
   % Edward N. MacLeod

2. TeleRobotics International, Inc.
   7325 Oak Ridge Highway
   Knoxville, TN 37921
   (615) 690-5600
   % Daniel P. Kuban

3. Hittite Microwave Corp.
   21 Cabot Rd.
   Woburn, MA 01801

(617) 933-7267
% Brian Bedard

4. Spatial Positioning Systems, Inc.
   Innovation Center,
   1800 Kraft Drive
   Blacksburg, VA 24060
   (703) 231-3145
   % Eric J. Lundberg

5. Potomac Interface, Inc.
   1911 North Fort Myer Drive
   Arlington, VA 22209
   (703) 247-1955
   % Dr. R. B. Dillaway

6. TG&C Associates, Inc.
   One Cessna Drive
   Falmouth, VA 22405-1417
   (703) 371-3531
   % Dr. T. G. Horwath

7. Redzone Robotics, Inc.
   2425 Liberty Ave.
   Pittsburgh, PA 15222-4639
   (412) 765-3064
   % Ben Motazed

8. Computer Applications Systems, Inc.
   P.O. Box 251
   Signal Mountain, TN 37377
   (615) 752-1787
   John C. Thompson

9. Austin Telecommunications
   290 Prqtt St.
   Meridian, CT 06450
   (203) 630-1822
   % Neill Edwards

10. Vector Design and Manufacturing, Inc.
    3291 E. Hemisphere Loop
    Tucson, AZ 85706
    (602) 294-1410
    % Lee Smith

11. V.F. Warner and Associates, Inc.
2000 Corporate Ridge Drive
Suite 915
McLean, VA 22102
% Bruce Korda
VP International Programs

12. Oceaneering Technologies, Inc.
Attn: Susan H Gyldenege
501 Prince George's Blvd.
Upper Marlboro, MD 20772
(301) 249-3300

13. SRI International
333 Ravens Ave.
Menlo Park, CA 92025
(415) 326-6200
% Barbara E. Camph

14. Jet Propulsion Laboratory
Mail Stop 107-102
4800 Oak Grove Drive
Pasadena, CA 91109
% Larry Matthies

15. International Submarine Eng. Ltd.
1734 Broadway St.
Port Coquitlam, B.C.
Canada V3C 2M8
(604) 942-7577
% Eric Jackson

16. Kenetic Sciences Inc.
6620 N.W. Marine Drive
Vancouver, B.C. V6T 1Z4
(604) 822-5782
% Guy Immega

17. Lockheed Sandars, Inc.
Defence Systems Division
P.O. Box 868
Nashua, NH 03061-0868
(603) 885-4321
% Maryann Stuke

18. Harris Technology Inc.
12702 Chapel Rd.
Clifton, VA 22024
(703) 266-0900
% Jim Harris

19. Transition Research Corp.
Shelter Rock Lane
Danbury, CN 06810-8159
(203) 798-8988
% John M. Evans

20. FMC Corp.
Corporate Technology Center
1205 Coleman Avenue
Box 580
Santa Clara, CA 95052
(408) 289-2731
% Louis S. McTamaney

21. Robotic Systems Tech.
1110 Business Parkway South
Westminster, MD 21157-3065
(410) 876-9470
% Scott D. Myers

22. Penn State
Research Office Building
University Park, PA 16802-4710
(814) 865-1891
% H. Randolf Thomas, Jr.

23. Spar Aerospace Limited
9445 Airport Rd.
Bramton, Ontario
Canada L6S 4J3
(416) 790-2800
% Peter Kruse

24. Colorado State University
Dept. of Mechanical Engineering
Fort Collins, CO 80523
(303) 491-6558
% Justin Downs III

25. Fredrick Herold & Associates Inc.
7303A Hanover Parkway
Greenbelt, MD 20770
(301) 982-4001
% Lenn R. Fox

26. McDonnell Douglas Aerospace
Space Systems Division
13100 Space Center Blvd.
Houston, TX 77059-3556
(713) 244-4000

27. Allen Osborne Associates
756 Lakefield Rd.
Building J
Westlake Village, CA 91361-2624
(805) 495-8420
% Hans-Juergen Kunze

28. Gnostech Inc.
650 Louis Drive
Suite 190
Warminster, PA 18974
(215) 443-8660
% Alan D. Fesnak

29. Controlauto Systems, Inc.
305 Stonehindge Way
Nashville, TN 37221-4600

30. Arinc Research Corporation
4055 Hancock St.
San Diego, CA 92110
% L.E. Levenson

31. CAE Electronics Ltd.
8585 Cote de Liesse
C.P. 1800 Saint-Laurent
Quebec, Canada H4L 4X4
(514) 341-6780
% Carol Crawford

32. Alabama Agricultural and Mechanical University
Department of Physics
P.O. Box 1263
Normal, AL 35762
(205) 851-5870
% H. John Caulfield

33. Optical Shields, Inc.
1390 Willow Rd.
Menlo Park, CA 94025
(415) 323-8191
% Ronald Schrodeck

34. Barquist Engineering Co., Inc.
P.O. Box 949
Kelseyville, CA 95451
(707) 279-0323
% Wiliam S. Barquist

35. Now Solutions Inc.
3235 Kifer Rd.
Suite 355
Santa Clara, CA 95051
(408) 737-8841
% Ali Bologlu

36. Telestar International Corp.
P.O. Box 485
Walnut, CA 91788-0485
(909) 923-6999
% Frank Liu

37. Visidyne, Inc.
10 Corporate Place
South Bedford St.
Burlington, MA 01803
(617) 273-2820

38. BEI Motions Systems Co.
Precisions Systems and Space Division
425 W. Bonita Ave, #205
San Dimas, CA 91773
(501) 851-5476

39. Astronautics Corp. of America
P.O. Box 523
Milwaukee, WI 53201-0523
(414) 447-8200
% Daniel R. Wade

40. New England Manufacturing Co.
66 Bridge St.
Norwell, MA 02061
(617) 659-7504
% Phill Causer

41. Wright Laboratories
Robotics Laboratory
Building 9738
Tyndall AFB, FL 32403-5319
(904) 283-3725
% Edward Brown

42. Ohio State University
Center for Mapping
1216 Kinner Rd.
Columbus, OH 43212
(614) 292-1600
% George Dedes

43. Trimble Navagation
9750 Third Ave. N.E.
Suite 306
Seattle, WA 98115
(206) 526-8638
% Doug Merrill

44. Magnavox Government & Industrial Electronics Co.
2829 Maricopa St.
Torrance, CA 90503
(310) 618-7319
% Charles M. Wohl

45. Trellis Software & Controls, Inc.
2619 Product Drive
Suite 106
Rochester Hills, MI 48309-3807
(313) 853-0700
% Brian P. Demoe

46. North Carolina State University
Civil Engineering Dept.
Box 7908
Mann Hall
Raleigh, NC 27695-7908
(919) 515-3677
% Leonhard E. Bernold

47. Del Norte Technology, Inc.
1100 Pamela Drive
P.O. Box 696
Euless, TX 76039
800-477-3524

48. Vehicle Monitor Corporation
6825 17th Ave NE
Suite 100
Redmond, WA 98052
(206) 881-5560
% Mike Van Schoiack

49. Southwest Research Institute
6220 Culebra Road
PO Dr 28510
San Antino, TX 78228-0510
(210) 685-5111
% James A. Lukemeyer

Appendix M

Functional and Operational Requirements for the Collision Avoidance System

Appendix M

Functional and Operational Requirements for the Collision Avoidance System

M-1. INTRODUCTION

The Idaho National Engineering Laboratory (INEL) has been tasked with demonstrating its ability to exhume buried transuranic, low-level, and mixed waste in support of the U.S. Department of Energy (DOE) waste management programs. The demonstration is scheduled for fiscal year (FY) 1995 and will involve a full-scale burial pit mock up of simulated waste. The demonstration exercise will be conducted inside a large shelter covering the burial pit, which is a nonhazardous, nonradiation environment. Remotely operated systems will be used for waste retrieval and will include

1. Excavation system: A Caterpillar 325 or equivalent, operating tethered, with special end effectors to retrieve and dump the expected variety of waste. The excavation system will have a remote operator but may also be capable of semiautonomous and/or autonomous control.

2. Gantry crane: A tethered overhead crane that spans across the pit 60 ft and overhangs beyond the pit 20 ft. The gantry crane will provide lifting devices and dual manipulator arms to support work in the dig area. The crane will travel the length of the dig area on ground level rails. For the FY-95 demonstration, the gantry crane will be remotely operated. The crane deploys the digface characterization system, contamination control system, vacuum system, grouting system, wastestream sorting, and miscellaneous small tools.

3. Conveyance system: A semiautomated (possible fully automated) waste container conveyance system that travels over a variety of terrain. The system will be untethered with all control and data communication using radio link by a remote operator.

4. Human Engineered Control System (HECS): Retrieval operations will be controlled from operator stations located in a remote shelter no more than 500 ft from the dig area. The HECS design team is responsible for determining the full details of the operator interface, including the number of operators, specific operator functions, how they perform their functions, information they require, how the information will be presented to them, all data input/output (I/O) requirements to and from the operator stations, and operator environment such as heating, ventilating, and air conditioning (HVAC).

The operator requirements defined to date include two operators stations for the gantry crane functions, one operator station for the excavator, and one operator station for the supervisory control system (SCS). The conveyance system will require an additional operator station if it is semiautomated; if fully automated, it will be integrated into the supervisory or gantry crane control station. Additionally, a digface characterization control station will be included as part of the HECS. Geophysicists working at this station will process and interpret the raw characterization data and will have the ability to pass their interpreted results through the SCS to the retrieval systems operators.

An example of characterization data is predictive maps of the buried waste beneath the digface that offer clues to the operators of how best to proceed with the excavation. A recorder station will also be required for logging visual observations concerning the nature of the retrieved waste.

5. Supervisory Control System: The SCS is a subset of the HECS. The SCS monitors and supervises the remotely controlled equipment, providing collision protection, video monitoring control functions, and a data distribution highway between the containment building and remote control shelter. The SCS operator will be the supervisor of all retrieval operations.

The operational scenario for the FY-95 demonstration is to retrieve simulated waste buried belowgrade. The requirements for waste transport from belowgrade to abovegrade for conveyance system access are not yet solidified. It is likely that this function will be performed by the gantry crane using teleoperation as follows: The crane will obtain empty waste containers from a supply of containers stacked in the building; the crane will position empty waste containers belowgrade as needed for the excavator; the crane will retrieve the filled containers and place them abovegrade in a location compatible for pickup by the conveyance system.

As waste containers are filled, the operator at the recorder station will record visual observations concerning the nature of the retrieved waste as obtained from video displays. The recorded data will be tagged with the box serial number. It shall be possible for the digface characterization data, as processed and interpreted by the geophysicists, to be included with this data file. As part of future retrieval, some form of assay/sort system is being considered.

The scope of this document is limited to the functional and operational requirements of the SCS. The development strategy for the SCS is to realize a base system integrated from existing technology. The base SCS will provide the initial primary supervisory control functions. This initial, modest system shall be designed for future evolution of advanced technology required for more sophisticated SCS monitoring and control. This document describes the requirements of the base SCS only. It does not describe the anticipated future enhancements but rather describes the open system architecture required for such enhancements.

M-2. SCS OBJECTIVES

The ultimate goal of the SCS is to provide features of remote-controlled work system supervision that is sufficient for operation comparable to "the man in the cab." To achieve this goal, the SCS will provide the following:

1. Advanced features for information processing, control, and display that increase the operator's perception and functionality and offer a more natural interface with less operator training. The SCS will enhance the control of all remotely operated systems related to each other and the retrieval environment.

2. Automatic features of collision avoidance, consisting of detection, alarming (features of advanced operator perception), and automatic shutdown. Automatic override features are included to provide routine operational evolutions of necessary contact.

3. Communications and data highway system between the waste retrieval equipment and HECS. This system shall provide data exchange between all equipment required to share and integrate data. Examples of shared data include video, digface characteristics, machine health, and waste sorting.

M-3. BASE SCS OPERATIONAL REQUIREMENTS

The base SCS shall have the following operational requirements:

1. Video displays for the SCS shall be an integral part of the HECS. The SCS displays will be located in the HECS remote shelter.

2. A primary task of the SCS is collision avoidance. The collision avoidance system shall prevent or minimize equipment damage due to inadvertent contact with other equipment or obstacles; prevent the loss of environmental containment; and provide an aid in the navigation of mobile vehicles.

3. The collision avoidance operational boundaries shall be the inside structure of the containment building currently defined as being no greater than 200 ft on each side.

4. If the remotely operated systems have position data or joint resolver data available, it shall be provided to the SCS. The resolution and sample rate shall be sufficient to allow real time 3-D modeling of the work area. For the remotely operated systems, the position resolution shall equal or exceed ± 2 in., and the sample rate shall equal or exceed 200 samples per second. The remotely operated systems for the FY-95 demonstration are the excavator, conveyance system, and gantry crane. The position and orientation data for the gantry crane shall be transferred directly from the gantry crane control system to the SCS.

5. Any equipment or obstacle that has no position sensing or joint resolver capability shall use a stand alone position sensing system that shall be independent of any teleoperated mobile system in operation within the retrieval area. Data from the position sensing system shall include the location of immobilized obstacles that are significant for collision avoidance. The location and orientation data shall be of adequate resolution and sample rate to allow real time 3-D modeling of the work area, including significant obstacles. For mobilized equipment, the resolution and sample rate shall equal or exceed ± 2 in. and 200 samples per second. For immobilized obstacles, the resolution shall equal or exceed ± 2 in., with model updates each time an obstacle is moved. Examples of obstacles in the retrieval environment that will require collision avoidance are the edge of the waste pit, waste retrieval containers, continuous air monitor systems (CAMS), and relocated "large objects."

6. A scanning system shall be supplied that functions on demand or automatically to give a coarse 3-D rendering of terrain and contour of the dig area.

7. 3D modeling software shall use the position sensing and terrain scanning data to generate a real-time 3D model of the retrieval environment for the purpose of overall operator perception and collision avoidance. (This is not intended for high resolution geophysical

scanning of limited areas of the digface. This function is the responsibility of the Digface Characterization System).

8. The SCS shall use the 3D model data to generate, in real time, a high quality collision avoidance rendering of the excavation process. This image shall provide interactive collision detection and avoidance information. 3D displays shall be capable of providing several different views of the excavation area. Collision alarms shall be integrated into the display system.

9. The SCS shall use the 3D model data to compute expectations of collisions and issue alarms to operators via operator display. The expected collision shall be highlighted on the display to increase operator perception of the problem.

10. The SCS shall issue a shutdown signal (fail safe contact open or closure) to any remotely operated system whose position indicates that a collision is imminent. The operator display shall alarm to indicate the automatic action taken.

11. The SCS shall incorporate operator adjustable automatic override features for operations involving routine collision scenarios, such as the excavator end effector contacting the digface, and the gantry crane manipulator arm positioning a waste container. The override shall disable the audio alarms and automatic shutdown associated with the specific scenario. The override feature shall not be in effect when the collision scenario appears out of sequence in a different operational evolution. For example, the gantry crane, while moving a CAM could collide with a waste container.

12. The SCS shall include a high quality video system with video cameras deployed within the containment building. Its function shall be to provide the operators with an overview of the location and movement of all remotely operated systems and obstacles.

13. One of the primary functions of the SCS is to provide data exchange between the HECS and retrieval equipment. This shall be accomplished over a broadband communications network so that data and video can be efficiently transferred from the containment building to the HECS shelter and shared by the various systems. This system will offer interface enclosures at the containment building and at the HECS shelter. The specific data exchange requirements are defined in the HECS Functional and Operational Requirements document.

14. The SCS shall offer a Transmission Control Protocol/Internet Protocol (TCP/IP) Ethernet network, or similar open, widely used, nonproprietary network within the operator control shelter to enable processors within the shelter to exchange data.

15. All SCS processors shall include communications boards and software to support the open network architecture. These processors shall include a real-time, multitasking operating system. It is preferable that this be a real-time UNIX-based system. The programming language shall be a high-level language, preferably C/C++. In all cases, the supplier shall obtain approval for any deviations from the preferred operating system, programming language, and processor type prior to incorporation into the SCS.

16. The SCS shall be implemented with a hardware/software architecture that is flexible, expandable, and compatible with the Sandia National Laboratory Generic Intelligent System Control (GISC) philosophy (hardware/software architecture so that it is possible to incorporate future advanced features of GISC.).

17. The SCS for FY-95 shall include standard off-the-shelf hardware/software from the supplier's normal product line as available.

18. The proposed systems shall be designed to require minimal calibration and maintenance once the system is installed and operational. Inadvertent and routine de-energizing of the equipment will not require recalibration. When calibration is required, it shall be an automatic function where practical.

19. All proposed systems shall be designed so that they can become "hardened" in the sense of operation and maintenance in a contaminated environment. However, for the FY-95 demonstration, the operational environment shall be nonhazardous. Access to the operational environment will require the use of a bubble suit to simulate a contaminated environment.

20. The proposed systems shall be designed to operate in a dusty and dirty environment and will allow minimal outside intervention once the system is in operation.

21. The SCS shall have an integrated diagnostics system that periodically checks all SCS major subsystem elements for failure. Failure detection shall result in an alarm to the operators and shall be reported at a diagnostics terminal. The alarm shall inform the operators which SCS function has been impaired by the failure. The diagnostics system shall allow a qualified SCS maintenance operator to run software driven diagnostic routines identifying the specific line replaceable module that has failed.

22. All proposed radio communications channels will be identified to allow an orderly frequency assignment by the INEL frequency manager through the appropriate regulating agency. Radio frequency shall not be used by the SCS for data communications but may be used for position sensors if necessary.

M-4. BASE SCS FUNCTIONAL CONFIGURATION

The following descriptions detail each section of the base SCS including video monitoring, broadband data highway communications, tracking and positioning, digface area scanning/mapping, software modeling, computer network, status alarms, and user interface.

M-4.1 Video Monitoring

Each remote system involved in the retrieval process will be equipped with video cameras to monitor their specific operations and control scenario. In addition, the SCS will have video cameras to monitor the entire retrieval process from an external view. It is anticipated that the SCS will use a minimum of eight video cameras. The exact quantity will be determined by the HECS design based on human factors engineering and on the scale of the initial demonstration.

The SCS video cameras shall be strategically mounted so that all areas of the retrieval operation can be observed. Each camera will be rigidly mounted to the internal structure of the excavation building or remote system. Locations for the SCS cameras will be determined by the HECS design based on human factors engineering. Each SCS camera installation shall be engineered to provide protection from external damage. For the demonstration, design features preventing the collection of dust, dirt, and moisture on the lens of the camera are not being considered; however, for future production retrieval activities, these aspects must be included.

Control of pan, tilt, zoom, iris, and focus for SCS camera scenes will be the primary responsibility of the SCS operator (supervisor). Because multiple cameras will require controls, features shall be implemented that permit a single controller at each operator station to be switched for controlling any SCS camera as required. This will eliminate the number of camera control units mounted on the operator control consoles. The SCS operator, who acts as a supervisor to retrieval functions, will assign control of SCS cameras to the other system operators as required. This will allow the various operators to control the SCS cameras assigned to their specific retrieval process using their single-switched camera controller.

Each SCS video signal will be modulated on a broadband data highway connecting the retrieval area to the HECS. The channel bandwidth for each of the video signals on the broadband data highway shall be compatible with NTSC composite video (video compression shall not be used). Each video signal on the broadband system will be assigned a channel that can be displayed independently and simultaneously on each operator's monitor as required. This will allow the SCS operator, as well as any other operator, to observe video information from the SCS and other camera systems.

The type and quantity of lighting projected on the retrieval operation is critical to the proper acquisition of video data. Operator perception of perspective, contrast, and depth of field can be greatly enhanced by the proper lighting. The design of the SCS system will take into consideration these important aspects of lighting. Remote control of area and spot lighting shall be included as part of the SCS task and controlled by the SCS operator.

Control of each SCS camera is seen as operator time intensive. Therefore, selected SCS camera controller shall be provided with an operator option of automatic tracking of unique targets located within the retrieval environment. This system shall permit the SCS operator to assign each camera a specific location to be automatically tracked (such as a target located at the end effector on the gantry crane). Assignment shall be controlled by the SCS operator through a pull down menu on the SCS collision avoidance system. Features shall be provided to preprogram several different multicamera configurations that can be initiated during different retrieval operations. Auto iris and focus systems shall also be employed.

M-4.2 Broadband Data Highway

The SCS will implement a common communications transmission and distribution network for video and data that are available to each remote system. This distribution network shall equal or exceed the performance of a mid-split, 5 MHz to 550 MHz, broadband, single cable (such as co-axial, tri-axial, and fiber) communications system. This broadband network shall have the capacity to carry all externally directed and intersystem digital data, including all analog video up to 50 channels. The design must consider the radio frequency environment of all systems and ensure interference does not adversely affect operation.

The data highway shall have the ability to distribute signals between the excavation area and the control shelter at distances of up to 500 ft using a single cable (copper or fiber).

The data highway shall have the capability to support the controlled sharing of data between systems, by featuring selected channels of data on the network accessible by multiple users. It shall also feature secure selected channels for access only by critical systems.

This system will include interface racks within a shelter at the containment building and corresponding interface racks within the HECS shelter.

M-4.3 Tracking and Positioning of Remote Mobile Platforms

To assist in the early detection of possible collisions and aid in navigation, the base SCS shall incorporate position sensing technologies to locate and orient mobile equipment and immobile obstacles within the excavation area. The conveyance system, gantry crane and excavator may include position data as part of their integrated design features. If this information is available, it shall be transferred to the SCS. All systems that do not include integrated position data shall rely on the SCS position sensing system. The SCS position sensing system shall include strategically located positioning beacons that are mounted on each mobile platform and multiple beacon sensing receivers located on the periphery of the dig area. The several sensing receivers will identify relative distance to the beacon or beacons. The host processor will calculate the "XYZ" coordinates of the beacon or beacons located on the equipment.

From the position sensing data and with each platform located via its beacons, computer modeling of both the platform and exclusion zones surrounding the platform shall be generated and maintained by the host processor. This modeling information shall be used to perform collision avoidance tasks. Other than the beacons, joint resolvers, and data collection/communications, no tracking and positioning processing equipment shall reside on the mobile platform. This does not include equipment provided as part of the remotely operated system.

The primary task of the position tracking system shall be to accurately track in 3D real space, the several systems involved in the excavation process. The tracking system shall be capable of providing sufficient positioning sensors on each platform to allow the modeling system to define position, orientation, and attitude in real time of the several mobile or moveable platforms in the dig area. The tracking system shall provide the following features:

1. The system shall be capable of locating beacons, sensors, or reflectors located on each mobile or moveable platform to an accuracy of at least ± 2 in.

2. The system shall be capable of an aggregate acquisition rate sufficient for the XYZ position of each sensor to be read at a minimum rate of 200 times each second.

3. The system shall be capable of acquiring and processing positioning information from a minimum of 30 sensors.

4. The system shall receive joint resolver data from the mobile platforms (i.e., conveyance, excavator) and shall receive absolute position, configuration, and orientation data from the gantry crane.

5. All positioning data acquired shall be stored in data files capable of being accessed by the modeling processes, on-line and in real time. In addition, current data shall be stored in a buffer so that a 10-minute history of all position data is memory resident and available at any time to be transferred to a permanent data storage.

6. System operation or data accuracies shall not be significantly impeded by a dusty and noisy environment (electrical and acoustical noise).

7. Where tethers to the mobile platforms exist, space will be provided to facilitate positioning beacon or sensor wiring. On the untethered equipment, the position and mapping systems must use radio links, if needed, for telemetry. All systems proposed shall ultimately be capable of untethered operation, as the systems develop beyond FY-95.

8. The positioning system shall be capable of being calibrated and system accuracies verified by sampling sensors at known locations as part of each scan frame. System software shall be capable of rolling the calibration data back into the process to correct system errors through the use of a differential error correction and minimization scheme.

M-4.4 Digface Area Scanning/Mapping

A coarse, broad area terrain mapping system shall be provided for the purpose of operator awareness and collision avoidance (this is not for the purpose of high resolution limited area geophysical scanning). The mapping system shall be capable of near real time modeling of the dynamic digface terrain and floor area ahead of the scanning device. This includes defining unexpected obstacles that may be hazardous to the movement of the mobile platforms (e.g., waste containers, storage drums, boxes, uneven surfaces, and pits). A high scan rate for this system (200 times per second as with the mobile platforms) is not required since the expected rate of change of the terrain is very low. The mapping system shall satisfy the following requirements:

1. This system shall be capable of developing 3-D gridded contour maps of the XYZ dig floor and digface area. Multiple scanners may be needed to provide full coverage of the excavation area.

2. Over the area of interest, the contour grid lines shall be developed from XYZ points scanned as narrow as 12-in. increments with an accuracy of ± 2 in.

3. The scanning system shall be capable of scanning the dynamic changing contour of the digface being accessed by the excavator. The dynamics of the digface are for operator perception only and will not be used for collision avoidance. The collision avoidance region of the digface will be conservatively set ahead of the excavator. Thus, a high scan

rate is not required. The height of the digface ahead of the excavator shall not exceed 15 ft.

4. All positioning data acquired shall be stored in data files that can be accessed by the modeling processors.

5. The time required to scan the area of interest shall not exceed 5 seconds.

6. The system proposed shall have two modes of operation, an autoscan mode and a forced mode. Typically, the system will reside in a autoscan mode, which continually updates the area map every 5 seconds to 10 minutes, selectable by the user. In a forced mode, the system will update the map when requested.

M-4.5 Software Modeling

The software systems shall be capable of supporting 3-D computer modeling of the dig area and sensor-monitored components located in it, based on XYZ spacial location information provided by the positioning and surface mapping systems identified in Sections 4.3 and 4.4. The computer modeling information will support collision avoidance, navigation, contour mapping, and excavation history.

1. The software systems shall be capable of wire and/or solid modeling and displaying real-time locations, at computation update rates of 200 times each second (display update rates can be much less), of all monitored components of the excavation process. This shall include the (a) excavator, (b) conveyance system, (c) gantry crane, (d) digface (this is the coarse data not for geophysical survey), (e) containment structure, (f) all sensor obstacles, and (g) other fixed modeled obstacles.

2. The displayed models shall give sufficient detail to outline all prominent system boundaries on each monitored component so that the system is dynamic and easily recognizable.

3. The modeling software shall be capable of using mapping data, in real time, from the systems described in Section 4.4.

4. In addition to creating models of each monitored component, the modeling software shall create protection envelopes around each system in the dig area. These displays shall include color differentiated envelopes around each system to define "caution" and "imminent collision" zones. The size of these zones shall be direction of motion and speed of motion dependent. The outer or "yellow" zone is a caution zone, where an operator alert is issued when the zone is violated. The inner or "red" zone is the imminent collision zone, where operator action is required. The operator shall have the option of toggling "off" the display of the collision zones, and in that case, they shall automatically display when a collision zone is violated. The software shall provide user feedback, in the form of audible and visual warnings, if the envelopes should overlap. The user shall have the ability to acknowledge or override the warnings.

5. The software collision avoidance model shall incorporate operator adjustable override features for routine collision scenarios. This will allow operation where the remote systems must make physical contact (e.g., the excavator end effector contacting the digface and gantry crane manipulator arm positioning a waste container). The override shall disable the audio alarms and automatic shutdown associated with normal collision avoidance. The balance of the collision protection system shall remain in operation. The override feature shall not be in effect when the physical contact scenario appears out of sequence. For example, the gantry crane could collide with a waste container when repositioning a CAM.

6. The modeling display shall cover the whole dig area, with user selectable zoom, rotation, and viewing angle capabilities to allow closer detailed examination of selected areas of interest. The operator shall also have the capability to select from several predefined views of each remote system.

7. The display system resolution shall be no less than 1,024 × 768 with a minimum of 8 bit color.

8. Color assignments of the modeled environment shall be operator selectable.

9. The system software must be developed using a high-level language that is an industry standard running on a real-time multitasking industry standard operating system (proprietary languages or operating systems are unacceptable). It is preferred that all software be written in C/C++, running on a real-time, UNIX-based system. Communications between systems shall TCP/IP Ethernet protocol, or a similar open network architecture. Fully documented source code shall be provided for all software.

M-4.6 Computer Network

Typically all externally directed computer data traffic between systems will run on a common TCP/IP Ethernet link (or equivalent) carried on the broadband network.

Normal data exchange between all existing processor systems can typically be supported by one network, with the possible exception of passing and supporting real-time imaging and modeling data between systems. It is acceptable for the computer network configuration to include several networks to maintain isolation between systems if necessary.

The broadband has the capacity of carrying more than one independent network, as well as other direct data links capable of transferring higher speed data. The base SCS shall provide a TCP/IP Ethernet (or equivalent, nonproprietary network) carried on the broadband and distributed within the control shelter to allow communications and data exchange between systems.

M-4.7 BASE SCS User Interface, Status, and Alarms

The HECS team shall be responsible for designing the operator interface to the SCS. However, the following general computer interface features should be considered by the HECS designers. The SCS shall use "state of the art" high resolution color computer monitors for displays; a mouse, track ball, force ball, or joy stick for operator communications; and windows with icons and pull down menus for command options and built-in help. The displays of status and operator actions shall be efficient, clear, and intuitive. Normal operator to computer communications with the SCS (except for keeping logs) shall be the previously mentioned "point and click" type and not require a key board. System operators shall not require special computer skills or engineering skills beyond the high school level. The following SCS specific operator interface features shall be considered:

1. The SCS shall provide retrieval environment overview display that

   a. Shows the relative position of all remotely operated systems and obstacles.

   b. Shows alarm conditions graphically with audio warnings, as appropriate.

   c. Highlights moving remotely operated systems (with variations in the intensity of their normal color).

   d. Highlights potential collisions that have alarmed.

   e. Highlights potential collisions for which an automatic shutdown signal has been issued.

   f. Cues the operator with recommended actions for mitigating an alarm condition.

2. The SCS shall have computer control of the video displays with a "point and click" interface. It shall have the following operator interface features:

   a. Provide a computer graphics image overview that illustrates the retrieval environment with the options of the various video images as selection icons.

   b. Allow the operator to quickly comprehend the visual perspective of the options of video images including pan, tilt, and zoom status. The status of pan, tilt, and zoom shall be illustrated graphically and, as an option, available numerically.

   c. Allow priority control of pan, tilt, and zoom. This means that the excavator operator cannot pan, tilt, and zoom the cameras on the gantry crane but might have access to the images.

3. The SCS shall have on-line diagnostics and provide diagnostic alarms built into the displays when the system detects subsystem failures.

4. The SCS shall provide a separate diagnostics terminal where failure information is reported. The diagnostics terminal shall allow a qualified SCS maintenance operator to

run a multitude of software driven, troubleshooting diagnostics to identify the particular SCS subsystem module that has failed.

5. The SCS shall provide a text processing interface to operators that will allow them to keep logs, generate the data files of retrieved waste observations, and access data files from the SCS intersystem communications network (e.g., digface and machine health). Concepts involving the innovative use of multimedia voice annotation are acceptable.

6. The SCS shall provide the capability for operators to record video imagery of their operations for the purpose of keeping logs. A VCR system could perform this function. The image recording system shall be designed to clearly indicate to operators what is being recorded, the time until the recording media needs to be changed, and alarm when it needs immediate attention. The recording system should also time and date stamp video data. Additional header information along with the time and date stamp may also be considered. The HECS design may identify the need for a log-keeping station with a dedicated operator that would manage a number of recorders for the acquisition of video data. The operator shall generate log files that record observations of the remote operations.